Technical Report

Analysis of the Thermal Performance of Tierra I— A Low-Energy High-Mass Residence

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National Renewable Energy Laboratory

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Abstract

We designed a low-energy concrete house using passive solar strategies to consume 70% less heating and cooling energy than a base case that conformed to the 1996 Home Energy Rating System (HERS) and the 1995 Model Energy Code (MEC). The performance of this house was then evaluated using computer simulations and measured data.

The house, Tierra I, was monitored from July 22, 1996, through October 14, 1997. A Short Term Energy Monitoring (STEM) test was done November 19 to December 10, 1996. Computer simulations of the house were done using SUNREL, an updated version of the hourly data simulation package SERI-RES. The SUNREL model of the house was calibrated using both short- and long-term data.

The house achieved energy savings of 56%, 14% below the goal of 70%. The lower-than-expected savings resulted from problems with the window modeling. As a result, during the design phase the solar gains were overestimated, causing an underestimate in the level of insulation necessary to achieve the savings goal. For very low-energy passive solar buildings, it is apparent that very accurate window modeling is required. It also became apparent that accurate ground models are required as well because ground-heat loss accounts for a significant portion of the total heat loss in low-energy buildings. In general, as we design lower and lower energy buildings, the overall accuracy of modeling becomes more and more critical. The current generation of building energy simulation programs needs algorithm improvements with respect to some mechanisms of heat transfer.

Acknowledgments

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Chapter 1 – Introduction

1.1 Background on Residential Energy Use and Conservation

The energy crisis of the 1970s resulted in the development of a comprehensive energy policy to produce long-term solutions. The goals of the policy were: "adequate energy supplies, reduced dependence on energy imports, protection against the disruption of foreign supplies, and increased conservation and efficiency in end uses." Residential buildings use 57% of U.S. buildings' total energy, with single-family detached homes accounting for 71% of that total. This represents 11.07 quadrillion Btu at a cost of $68.86 billion in 1987 dollars. Heating and air-conditioning accounts for 43% of total residential energy use, appliances account for a further 40%, and the rest is used for heating water. Reducing energy in detached homes through energy efficiency and passive solar design would have a significant impact on total building energy consumption [1].

1.2 Project Objectives

Tierra I is the first in a series of technical evaluations with the objective of designing, building, and evaluating a high-mass passive solar house that uses 70% less heating and cooling energy than a Home Energy Rating Council (HERS)[2] Model Energy Code (MEC)[3] base case house. An energy computer simulation was used to evaluate design options. This process is documented in *Tierra Concrete Homes: Low-Energy Residential Building Design* [4].

1.3 Specific Areas of Investigation

The objectives of this report are follows:

1. Describe the design and construction methods used for Tierra I.
2. Quantify the performance of Tierra I using short- and long-term data.
3. Model the house and determine base case heating and cooling loads using the hourly simulation package SUNREL. [5]
4. Examine the differences between the computer model predictions and measured performance.
5. Determine areas of success as well as those areas requiring further work to meet the goals of a house using 70% less heating and cooling energy than a HERS/MEC base case.

1.4 Report Organization

Chapter 2 describes the house, the site, and the climate. It also provides construction details and costs.

Chapter 3 describes the computer simulation work. It compares the base case energy use with the estimated energy use of the simulated design model. It also discusses the differences from design results and provides information on calibrating the model based on the measured data.

The long- and short-term data collection and instrumentation are discussed in Chapter 4. The Short Term Energy Monitoring (STEM) data are used to evaluate the solar performance and the building thermal envelope. The long-term data are examined to determine the energy performance of the house and compare it with modeled data. A section on infrared analysis corroborates the findings on the house's thermal envelope performance.

Chapter 5 discusses several issues resulting from monitoring and modeling the house. The section on re-optimization shows that the 70% savings goal could be achieved with more insulation. This chapter also summarizes the results and conclusions.

Chapter 2 – Building Features

2.1 House Description

The Tierra I concrete house is a single-story, three-bedroom ranch design that maximizes solar gain by orienting the long axis of the house east-west (see Figure 1). A clerestory increases the passive solar collection area and provides daylighting for the northern half of the house. The total living area is 1,870 ft^2 (174 m^2) with a two-car garage attached to the west side of the house (see Figure 2).
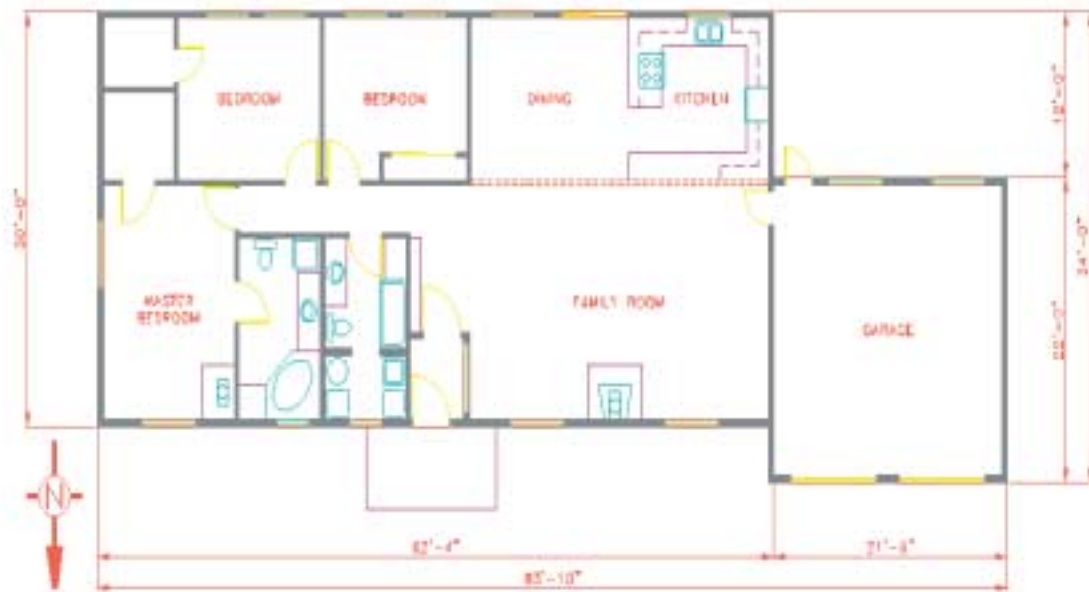
Figure 1. Tierra I floor plan

Figure 2. Tierra I—south side showing the garage (left) and main house with clerestory (right)

2.2 Site

Tierra I was constructed by Tierra Concrete homes in West Pueblo, Colorado. The elevation is 4,950 ft (1,509 m), the latitude is 38.18°N, and the longitude is 104.3°W. The building lot is flat with sparse vegetation, and there are large open areas between the neighboring houses. Landmasses and neighboring buildings do not provide any shading to the site.

2.3 Climate

Pueblo's climate is mild with moderate temperatures throughout the year. The 30-year average daily high is 68.6°F (20.3°C) and the average daily low is 36.8°F (2.7°C). There are 5,413 heating-degree-days (65°F base) and 973 cooling-degree-days (65°F base). The average daily solar radiation incident on an unshaded horizontal surface is 1,570 Btu/ft^2 (17,835 kJ/m^2).[6]

Table 1 shows monthly solar radiation and ambient temperature statistics. Table 2 contains statistics on wind speed, humidity ratio, ground temperature, and degree days. The information in both tables is from the output of SUNREL (the simulation package used for modeling in this report) and is derived from the Pueblo Typical Meteorological Year (TMY) weather files [6].

Table 1. Solar Radiation and Temperature Information

	Solar Radiation					Temperature			
	Direct	Unshaded	Direct	Diffuse	Total	Mean	Min.	Max.	Range
	Normal	Horizontal	Horizontal	Horizontal	Horizontal				
Month	kBtu/ft^2	kBtu/ft^2	kBtu/ft^2	kBtu/ft^2	kBtu/ft^2	°F	°F	°F	°F
JAN	55.42	26.96	21.08	5.88	26.96	26.9	-25.1	64.9	28.5
FEB	54.48	32.90	25.07	7.83	32.90	34.8	-18.0	75.9	29.3
MAR	64.48	50.01	35.66	14.35	50.01	38.1	-8.0	78.1	26.5
APR	62.55	58.19	40.34	17.85	58.19	50.5	16.0	79.0	27.5
MAY	67.72	68.99	47.89	21.10	68.99	62.1	34.0	88.0	29.0
JUN	76.42	75.09	55.99	19.10	75.09	71.2	46.9	95.0	30.7
JUL	72.65	71.71	53.37	18.34	71.71	75.6	55.9	97.0	27.7
AUG	70.07	64.13	47.95	16.18	64.13	74.7	55.0	100.0	29.1
SEP	63.55	52.28	38.59	13.69	52.28	65.8	33.1	96.1	28.9
OCT	64.62	42.89	32.33	10.56	42.89	56.7	28.0	88.0	34.6
NOV	52.46	28.83	21.53	7.30	28.83	42.1	19.0	72.0	29.5
DEC	52.70	24.83	19.04	5.79	24.83	34.6	0.0	69.1	33.9
TOT	757.12	596.79	438.84	157.96	596.79	52.8	-25.1	100.0	29.6

Table 2. Monthly Weather Data Showing Wind Speed, Dew Point, Humidity, and Degree Days

	Wind Speed				Humidity	Degree Days	
	Mean	Min.	Max.	Dew Point	Ratio	Heating	Cooling
						65°F Base	65°F Base
Month	Mph	Mph	Mph	°F			
JAN	6.4	0	36.9	16.6	0.0025	1151.8	0.0
FEB	8.6	0	27.7	17.9	0.0025	828.2	0.0
MAR	8.2	0	42.5	22.7	0.0032	822.2	0.0
APR	10.9	0	28.9	27.2	0.0038	450.7	0.0
MAY	12.2	0	34.4	32.4	0.0049	141.8	32.3
JUN	11.4	0	28.9	42.3	0.0071	8.0	168.8
JUL	9.2	0	38.0	48.2	0.0088	0.0	320.2
AUG	7.6	0	42.5	50.2	0.0094	0.0	309.8
SEP	9.1	0	40.3	40.6	0.0066	111.1	127.1
OCT	7.9	0	38.0	24.5	0.0033	248.3	9.0
NOV	7.6	0	30.0	21.3	0.0028	643.2	0.0
DEC	8.3	0	34.4	13.6	0.0020	902.2	0.0
TOT	8.9	0	42.5	29.9	0.0048	5307.7	967.3

2.4 Construction Methods

Tierra I was constructed with pre-cast concrete walls (see Figure 3). Most of the exterior and interior walls were poured off site and transported to the building location, where a crane lifted them into place. The pre-cast walls included openings for doors, windows, electrical conduit, and outlet boxes. All interior wall surfaces were finished to look and feel like drywall. The roof is constructed with raised-heel trusses, drywall ceiling, and blown-in fiberglass insulation.

Figure 3. Pre-cast concrete walls being set up

Polyisocyanurate insulation was secured to the outside surface using connectors (see Figure 4) when the walls were being cast. This was done by first laying the insulation down with inserted clasps. The concrete was then poured over the insulation and hardened around the clasps. Once on site, a concrete-based stucco finish was applied to the outside of the insulation on a mesh secured to the clasps. Other finishes, such as face brick or siding, may also be applied.
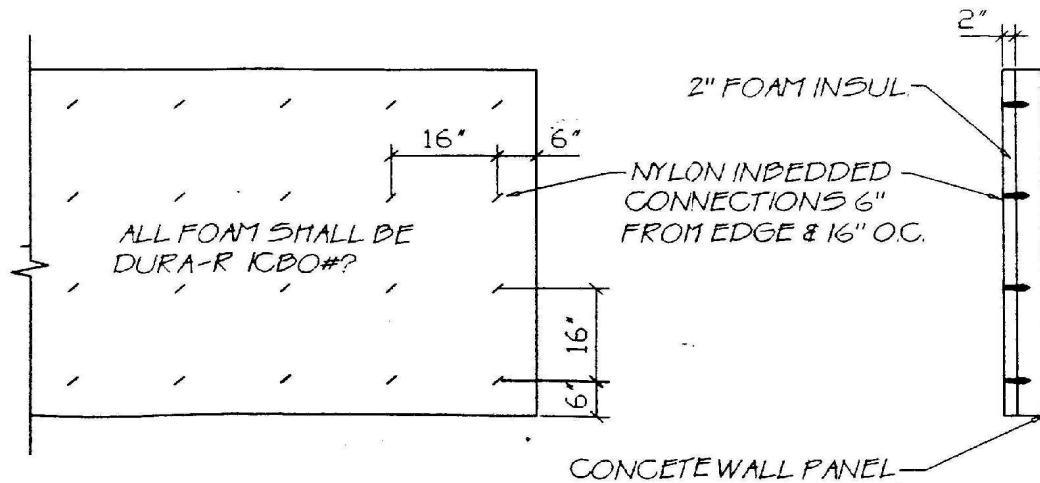
Figure 4. Wall insulation detail

Tierra Concrete Homes buys leftover and returned concrete from a local concrete plant. Returned concrete is poured into wall forms at the concrete plant rather than discarding the concrete or creating river riprap. Tierra purchases enough waste concrete to complete one house per week. Another feature is minimal construction waste (see Figure 5) because the walls include insulation and interior finish and minimal drywall and framing is used.

Figure 5. Dumpster with all construction waste including that from framing and drywall

2.5 Construction Costs

At $75/ft^2 ($807/m^2), excluding land, the cost of this passive solar concrete home is similar to that of other custom homes in the area, which cost $75 to $82/ft^2 ($807 to $883/m^2). Insulation costs (wall and perimeter) and the concrete walls are higher than the cost of typical wood-frame construction. In the Tierra house, the foundation (not insulated in typical Pueblo construction) costs $0.43/ft^2 ($4.73/m^2) to insulate, and the wall insulation costs $0.65/ft^2 ($7.00/m^2). This compares to $0.33/ft^2 ($3.55/m^2) for the wall insulation used in wood frame construction. However, significant savings are achieved through reduced construction time, limited use of drywall, and no central heating or cooling systems. A $1,000 propane stove and a $1,000 propane fireplace replace the conventional heating, ventilation, and air-conditioning (HVAC) system with ductwork.

2.6 Design Concept

This section examines the design and the energy-efficient and solar energy features of the 1,870-ft^2 (174-m^2) Tierra I house. The design is based on previous optimization work done on a smaller 1,120-ft^2 (104-m^2) house design that was never built [4].

2.7 The Design Team

Architectural design: MJC Consulting
         P.O. Box 1897
         Pueblo, CO 81002-1897
         (719) 546-2523
Energy design: Tierra Concrete Homes
         P.O. Box 1924
         Pueblo, CO 81002
         (719) 947-3040
Monitoring and testing: National Renewable Energy Laboratory
         Center for Buildings and Thermal Systems
         1617 Cole Blvd.
         Golden, CO 80401
         (303) 384-7538

2.8 Energy Conservation Features

- Air tightness: The concrete construction has little leakage, thus reducing energy loss resulting from infiltration. The design infiltration rate of the Tierra I house was 0.25 air changes per hour (ACH) and the measured rate is 0.2 ACH (see section 4.7).
- Daylighting: The design allows more daylight into the house to offset electric-light use and to promote a more pleasant atmosphere.
- Natural ventilation: The house uses natural ventilation to circulate cool night air during the summer, which is stored in the concrete to provide cooling during the day.
- Shading: Overhangs are sized to shade windows from direct summer solar gains, thereby reducing cooling loads.
- Solar heating: The building is oriented to maximize solar gain, which offsets heating loads.
- Thermal capacitance: The large interior concrete mass stores heat in winter and cold during the summer, which provides thermal comfort by reducing temperature swings.
- Windows: The windows are selected by their thermal resistance and shading coefficient (SC) for optimal thermal performance.

2.9 Building Specifications

A key aspect of energy-efficient building design is reducing energy use. Insulation is fundamental because it reduces heat loss in winter and heat gain in summer. Insulation levels for Tierra I are based on the levels determined during the design process. The roof sections are pre-engineered raised heel-trusses with R-38 ft²·°F·hr/Btu (6.70 m²·K/W) cellulose insulation. The wall insulation is R-14 ft²·°F·hr/Btu (6.70 m²·K/W). Windows are double-pane, low-E, with a rated SC of 0.84 and a U-value of 0.35 Btu/hr·ft²·°F (2.16 W/m²·K). The window specification required a trade-off between energy conservation (low U-value) and the desire for high solar gains (high SC). See Appendix B for a description of SC.

Additional energy savings are achieved through low infiltration levels. The concrete construction and solid insulation provide an airtight building with a measured value of 0.2 ACH. This translates to about 62 cfm (29 L/s) of outside air for Tierra I, which satisfies the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) standard 62-1989 [7] requirements of 60 cfm (28 L/s) for this house.

Energy-efficient, compact fluorescent lighting fixtures were installed throughout the home to reduce electric loads and, consequently, cooling loads. The house also uses low-flow faucets and showerheads that save energy by reducing hot-water consumption. The property is xeriscaped [8] for low water usage.

2.10 Climate Sensitive Envelope

Tierra I's design incorporates solar concepts to decrease heating and cooling loads. The house is oriented with the long axis running east–west to maximize southerly sun exposure. Glazing on the south side captures sunlight from the low winter sun to passively heat the home. A clerestory on the south brings in additional heat and daylight to the north side of the house. Overhangs are used to shade the windows from direct sunlight in the summer (see Figure 6) to reduce cooling loads. Figure 2 shows that the overhangs completely shade the south windows in the summer, reducing unwanted solar gains. To prevent unwanted gains from the low afternoon sun during the summer, there are no west-facing windows.

Figure 6. Overhangs shading south glazing in summer

Concrete walls and floors act as heat storage for solar gain. During the winter, these massive surfaces absorb solar heat during the day and radiate it back at night. In the summer, the heat sink works to absorb excessive heat during the day and release it to the cooler night air using natural ventilation.

Tierra I was designed with an open floor plan to encourage natural air circulation. Ventilation cools the house by bringing in the cool night air during the summer. Windows can be opened and closed as needed to assist air circulation and provide natural ventilation. The clerestory windows can be opened to encourage a stack effect, increasing the natural ventilation. Ceiling fans, located in every room, provide additional air movement and supplement natural ventilation.

2.11 Backup Heating Equipment

As a result of reduced heat loss and by using passive solar heating techniques, Tierra I has a small heating load. Two thermostat-controlled gas-fired units meet the heating load and code requirements for an automatic heating system. One unit is a propane gas stove (see Figure 7) and the other unit is a propane fireplace (see Figure 8). Heat is circulated using natural convection and ceiling fans.

Figure 7. Propane stove

Figure 8. Propane fireplace

Chapter 3 - Computer Modeling

3.1 Model Development

The performance of Tierra I was analyzed using the hourly energy simulation program SUNREL, an updated version of SERI-RES [9]. The first step in the process was to develop a base case model that met HERS and MEC guidelines. The base case simulation (model name: base case) provides the metric for judging Tierra I's performance. A pre-construction model (model name: pre-construction) was used to predict energy use and compare expected performance to the base case. After the house was built, the model was updated using the as-built characteristics (model name: as-built). The model was then calibrated (model name: calibrated) using measured data. Descriptions of all the models used are located in Appendix I.

3.2 Base-Case House Definition

The base-case house was modeled as a slab-on-grade, conventional wood-frame house with the same footprint as Tierra I. Working from the typical meteorological year (TMY) data file for Pueblo, the number of heating-degree-days on a 65°F (18.3ºC) base was determined to be 5,308°F·days, and the number of cooling-degree-days 967°F·days. To comply with HERS and MEC 1993 standards using these degree-days, the following was required:

1. Glazing area = 18% of the floor area equally distributed on all four facades. This gives 84 ft^2 (7.8 m^2) of windows per side, with 27% of that area attributed to window frames.
2. The overall wall U-value = 0.133 Btu/hr·ft^2·°F (0.757 W/m²·K). The specified opaque wall area R-value is 17.2 hr·ft^2·°F/Btu (3.0 m²·K/W). As a result, windows have a U-value of 0.4 Btu/hr·ft^2·°F (2.3 W/m²·K) for code compliance.
3. Roof R-value = 35.2 Btu/hr·ft^2·°F (6.2 W/m²·K).
4. Floor R-value = 4.5 hr·ft^2·°F/Btu (0.8 m²·K/W).
5. ACH = 0.67.

The house was assumed to have an HVAC system capable of meeting all heating and cooling requirements. Additional details on the HERS/MEC house development are available in Appendix C.

3.3 Occupancy Assumptions

The following values were chosen to reflect typical loads and thermostat settings in a residential space and are used for the base case as well as all the Tierra I models:

- The winter (September to April) heating set points are 65°F (18°C) from 10 p.m. to 5 a.m. and 70°F (21°C) at all other times.
- The summer (May to August) heating set point is 60°F (16°C).
- The cooling set points are 83°F (28°C) for winter and 78°F (26°C) for summer.
- The venting set points are 79°F (26°C) for winter and 68°F (20°C) for summer.
- Internal gains are scheduled at 1.27 kBtu/h (372 W) from 10 p.m. to 6 a.m. From 6 to 8 a.m. and from 6 to 10 p.m., internal gains are 4.24 kBtu/h (1243 W). From 8 a.m. to 6 p.m. internal gains are 0.39 kBtu/h (114 W).

Additional information on the development of the internal gain schedule is available in Appendix D.

3.4 Weather Data

The simulation requires weather data that are representative of long-term average patterns at the site. Such weather data are available for Pueblo in TMY and TMY2 weather files. SUNREL can use either type, but for consistency with the STEM work, which required TMY files, the simulations used the TMY data set. A site-specific TMY file was developed by merging the weather data measured onsite with the Pueblo TMY file. The model calibration process uses this weather file to compare the as-built model against measured data over specific time periods.

The Tierra I site-measured weather data are consistent with the TMY weather data for Pueblo. Figure 9 shows average monthly global horizontal radiation for the TMY and local data. The Tierra average radiation levels for the year are only 4% lower than TMY levels. The average monthly temperatures are lower than the TMY temperatures in the first half of the year and higher in the second half. (See Figure 10.)
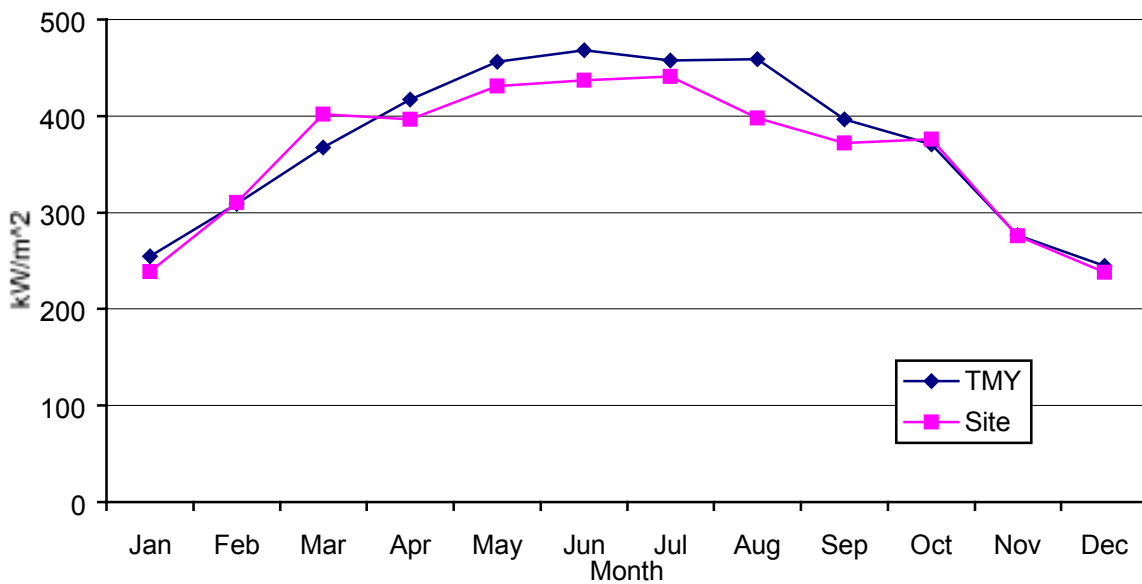
Figure 9. Average monthly global horizontal radiation
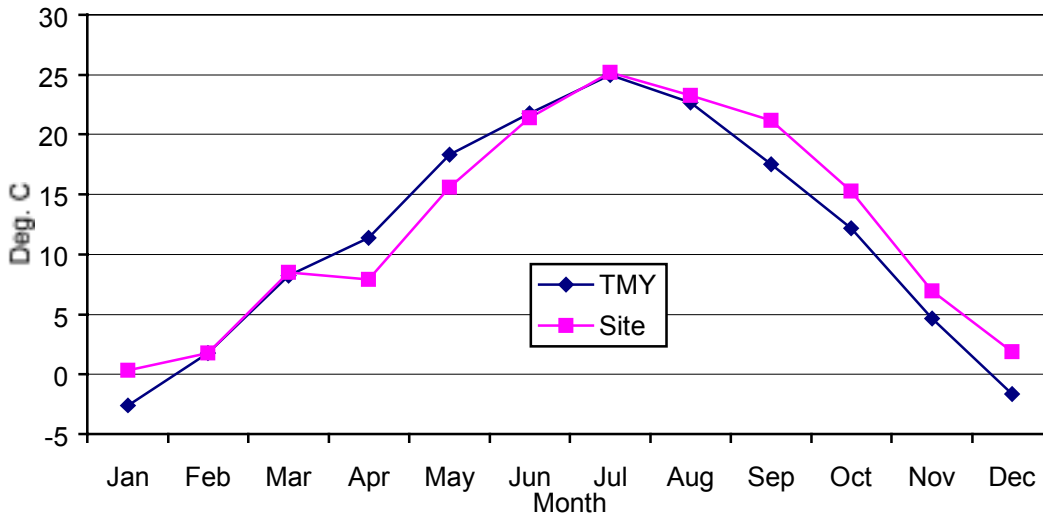
Figure 10. Average monthly outdoor temperature

3.5 Base Case Results

The base case heating load is 43.95 MMBtu/year (12.88 MW·hr/year) and the cooling load is 6.85 MMBtu/year (2.01 MW·hr/year). The cooling loads of the base case are quite low because ventilation works well in the Pueblo climate to offset cooling requirements. The slab-on-grade construction also helps reduce the cooling loads by acting as a thermal sink.

3.6 Tierra I Pre-Construction Model

Construction plans were used to make the pre-construction model of Tierra I for the next step in the computer analysis. This required appropriate occupancy assumptions and annual weather information for the site. The simulation of Tierra I provided performance predictions of the house. These results were compared with the base case to gauge house performance.

3.7 Results of the Thermal Analysis

The pre-construction simulation of Tierra I predicted an annual energy use of 15.50 MMBtu (4.54 MW·hr); 14.87 MMBtu (4.36 MW·hr) for heating, and 0.63 MMBtu (180 kW·hr) for cooling. This consumption level translates to roughly $93 per year for heating and cooling calculated at a cost of $6/MMBtu. The combined heating and cooling loads predicted by the pre-construction house are 69.5% lower than the base case loads (see Figure 11). Heating loads of the pre-construction model are 66% less than the base case while the cooling loads are 90% less, eliminating the need for mechanical cooling.
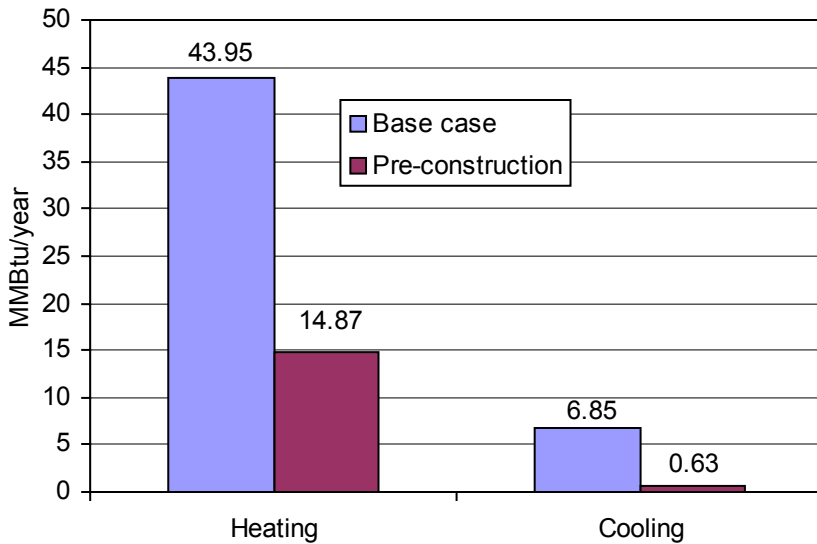
Figure 11. Base case and pre-construction model energy load comparison

3.8 Model Calibration

The pre-construction model provided a good preliminary assessment of the house performance. However, it needed to be updated after construction and then calibrated to the measured data. The post-construction model is called as-built and reflects changes between the pre-construction model and what was actually built. The main difference was in the glazing area. The as-built model has 7.6% less glazing than the pre-construction model.

To calibrate the as-built model, results were compared to data from two periods of the monitoring time frame. In the first period, November 23 through December 9, 1996, the house was heated with electric heaters used as part of the STEM testing. During the second period, January 1 to October 13, 1997, no heating, cooling, or ventilation was used, and there were minimal internal gains. The indoor temperatures were floating so the second period is labeled float. (See Table 4.)

Calibration adjusts various parameters until simulation results closely match measured data. Parameters were modified using STEM test results (see Chapter 4) as they indicate where the model is most likely under- or over-predicting. The STEM test indicated that the solar gains were only 73% of the model estimates. To account for the difference, the first modification to the model was to add artificial "screens" with a shading factor of 0.70, chosen because that value eliminated the solar gain error when used in the STEM model.

The output of the calibrated model with just the "screen" modification sufficiently matched the measured data (See section 3.9) that no other modifications were deemed necessary.

3.9 Calibrated and As-built Models Compared to Measured Data

Tables 3 and 4 compare the calculated heating requirements for the as-built and calibrated models to the measured values. Each table also shows the average of the hourly root-mean-squared (RMS) temperature error between predicted and measured values. The measured temperature value is the average of all the inside temperature measurements.

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Table 3. Heat Period—November 23–December 9, 1996

Case	Total Energy (KBtu)	Error	Temperature RMS Error (°F)
Measured	4368.0		
As-built	3040.8	-30.4%	2.4
Calibrated	3734.2	-14.5%	1.0

Table 4. Float Period—January 1–October 13, 1997

Case	Total Energy (kBtu)	Error	Temperature RMS Error (°F)
Measured	5748.0		
As-built	5753.7	0.1%	3.8
Calibrated	5753.7	0.1%	3.2

Table 5 shows the monthly temperature RMS error for the float period. The calibrated model error is less than 2.53 °F (1.41°C) for all but three months; January, February, and April. These months may have a larger error because snow may have changed ground reflectivity that was not measured by the horizontally mounted pyranometer. The incorrect radiation measurements, in turn, affected the modeling results.

Appendix H contains monthly graphs of the measured indoor temperature and the as-built and calibrated model temperature predictions as well as graphs showing rain and snowfall for each month. The as-built model tends to over-predict the temperature, while the calibrated model tends to under-predict . Based on these temperature trends, it seems likely that the actual annual heating load would fall somewhere between what the as-built and calibrated model predict.

Table 5. Coast Period Monthly Temperature Error

	As-built (ºF)	Calibrated (ºF)
Total RMS	3.81	3.22
Jan	3.14	5.81
Feb	2.96	5.88
Mar	6.77	2.53
Apr	4.04	3.30
May	2.89	1.14
Jun	3.53	1.78
Jul	4.02	2.25
Aug	1.97	1.14
Sep	2.57	1.48
Oct	4.26	1.35

3.10 Analysis of the Calibrated Model

The calibrated model predicts a heating load of 22.40 MMBtu (6.57 MW·hr) and a cooling load of 0.04 MMBtu (11.7 kW·hr) annually. This is a 56% savings compared to the base case, which is less than the

70% goal. A look at the segregated heat loss (See Figure 12) shows ground heat loss is the most significant followed by window and wall heat loss. Figure 13 shows that passive solar provides 50% of the required heating.
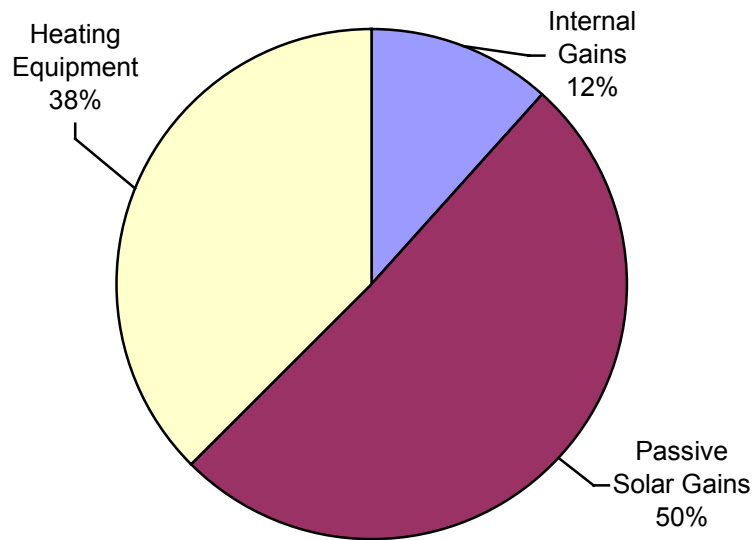
Figure 12. Segregated heat loss for calibrated model
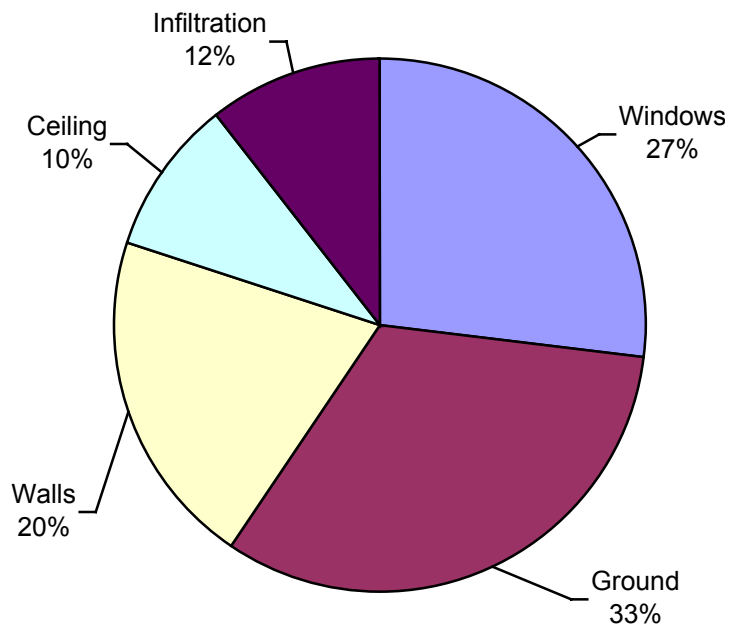
Figure 13. Breakdown of heat sources

CHAPTER 4 - Data Collection and Analysis

4.1 Data Monitoring Setup

Tierra I was monitored to validate simulations and evaluate its energy performance. Long-term data—measuring points inside the house and collecting outdoor weather and solar radiation information—was collected for over a year (see section 4.8.). Short-term data were collected for the STEM test over a period of a few weeks. (See section 4.4.)

4.2 Long-Term Data Collection

A data monitoring system was installed on July 22, 1996. The system used 17 channels to collect data in hourly increments. The setup was not complete until November 18, when the number of channels was increased to 19. Two channels were added for diagnostic information about the data recorder. Several other channels that had not been operating correctly were fixed. Monitoring continued until October 14, 1997, when the system was removed.

The monitoring system consisted of a Campbell Scientific CR-10X data recorder connected to a modem for remotely downloading data. The system installation included the following instrumentation:

1. Type T thermocouples to measure temperature within ±0.5°F (±0.28°C).
2. A Hall-effect watt-transducer to measure electric power within ±0.5% [11].
3. A Li-Cor Li200 pyranometer to measure solar irradiance within of ±3% [12].
4. RH sensor accurate to ±2% at 10% RH and ±3% at 90% RH [13].
5. RMYoung wind speed and direction sensor [14].

Table 6 lists the data record, which is a comma-delimited file with a one-line header. The channels are scanned every 5 seconds, averaged, and stored hourly. Appendix G contains the data logger program and a sample data record.

Table 6. Long-Term Data Acquisition Channels

Channel	Designation	Units	Comment
1	Log ID	N/A	Data logger identification information
2	Year	YYYY	
3	Day	XXX	1 = Jan. 1st etc. (Day Of Year)
4	Hour	Hours	0 to 2300
5	TCcsfam	°C	Black copper sphere (radiant temp.) family room
6	TCfam	°C	Thermocouple, family room
7	TCsmbed	°C	Black copper sphere (radiant temp.), master bed
8	TCmbed	°C	Thermocouple, master bedroom
9	TCbat	°C	Thermocouple, outside bathroom
10	TCbed	°C	Thermocouple, bedroom
11	TCdryer	Boolean	Dryer on/off
12	Solar_Rad	W/m^2	Global horizontal solar radiation
13	RHoutside	%	Outside relative humidity
14	TCoutside	°C	Outside dry-bulb temperature

15	Wind_SP	Mph	Wind velocity - mile per hour
16	Wind_Dir	Deg	Wind direction - degree
17	Total_Power	W	Total house electric power - watts
18	Tref	°C	Datalogger temperature (used for diagnostics)
19	Batt_V	V	Datalogger battery voltage (used for diagnostics)

4.3 Short-Term Data Collection

Short-term data (see Table 7) for the STEM test procedure were collected from November 19 to December 10, 1996, using a separate data logger from the one used for long-term data. Only indoor information was logged with the short-term monitoring equipment. All outdoor data needed for the STEM test is taken from the long-term data collection.

Table 7. Short-Term Data Acquisition Channels

Channel	Designation	Units	Comment
1	Log ID	N/A	Data Logger identification information
2	Year	YYYY	
3	Day	XXX	1 = Jan. 1st etc. (Day Of Year)
4	Hour	Hours	0 to 2300
5	T1	°C	Located in master bedroom
6	T2	°C	Located in bedroom
7	T3	°C	Located in bedroom
8	T4	°C	Located in dining room
9	T5	°C	Located in kitchen
10	T6	°C	Located in living room
11	H1	%	Fraction of hour electric heater # 1 was on
12	H2	%	Fraction of hour electric heater # 2 was on
13	H3	%	Fraction of hour electric heater # 3 was on
14	H4	%	Fraction of hour electric heater # 4 was on
15	H5	%	Fraction of hour electric heater # 5 was on
16	H6	%	Fraction of hour electric heater # 6 was on
17	TSet	°C	Temperature set point for heating
18	Tref	°C	Datalogger temperature (used for diagnostics)
19	Batt V	V	Datalogger battery voltage (used for diagnostics)

4.4 STEM Test

STEM tests provide an additional method of analyzing a house's performance. The STEM test is used to obtain the thermal parameters of a building, which can be used for long-term extrapolation [15]. The STEM method consists of two key elements: the test protocol and the analysis method. The protocol is designed to generate steady-state and transient data sequences that fit the requirements of the analysis method. The analysis method used in the STEM test for Tierra I is called primary- and secondary-term analysis and re-normalization (PSTAR), which provides a formal approach to the separation of cause and effect in the data [16].

Data for the STEM test are collected while the house is unoccupied to eliminate uncertainties caused by occupant behaviors. A typical STEM test requires only a few days, but because Tierra I was unoccupied, the data collection lasted several weeks. STEM test data were analyzed using the STEM 2.0 software

[17], which automates the analysis procedure. The software limited the number of analysis days to six. The data from November 25–30, 1996, were used because those data contained the necessary data sequences.

4.5 STEM Test Procedure

First, a one-time air pressurization and depressurization test was done using a blower door. The blower door test determined the building's effective leakage area (ELA). To perform this test, the doors, windows, and other openings in the house were closed, and a fan was used to pressurize the house (see Figure 14). The airflow rate was measured along with the inside-to-outside pressure difference. The ELA was estimated from a power-law curve fit of pressure difference plotted versus airflow rate (see Figure 17). It can be used to estimate infiltration based on stack and wind driving forces [18].

Figure 14. Blower door test setup

Next, a temporary data-acquisition system was installed and programmed with the test protocol to collect data. The protocol specifies a series of conditions controlled by turning electric resistance heaters on and off. The objective was to obtain data near a steady-state condition during the first night or nights (called the "co-heat" period) by maintaining a minimum indoor temperature using the heaters. The test procedure also specified cold outside temperatures. On subsequent nights, a cool-down period was initiated by turning the heaters off at midnight and recording the resulting temperature drops. Daytime data were used to determine the effect of solar gains. During the entire test, all house appliances and lights were turned off to reduce uncertainties [15,18].

4.6 STEM Software

The STEM 2.0 software incorporates the multi-zone PSTAR method to analyze the data and automate the process [19]. This method is based on an hourly dynamic energy balance equation for the house. The STEM 2.0 software uses a specially adapted SERI-RES audit model of the house as part of the input.

A second set of input is derived from the collected data. The methodology used by STEM 2.0 as well as the STEM procedure and the PSTAR method are described more fully in Appendix A.

4.7 STEM Output

The STEM testing produces several results. The first is the ELA determined by the blower door test. The other results are obtained from the STEM 2.0 software, which gives a renormalizing factor to three primary heat flows. The STEM software also plots the audit, renormalized, and measured indoor temperatures and heating loads (see Figures 15 and 16).
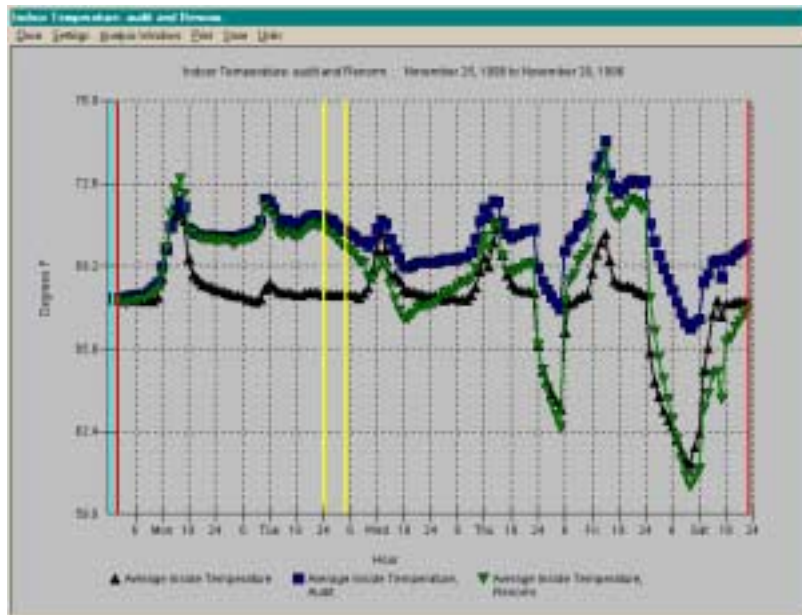
Figure 15. STEM inside temperature graph
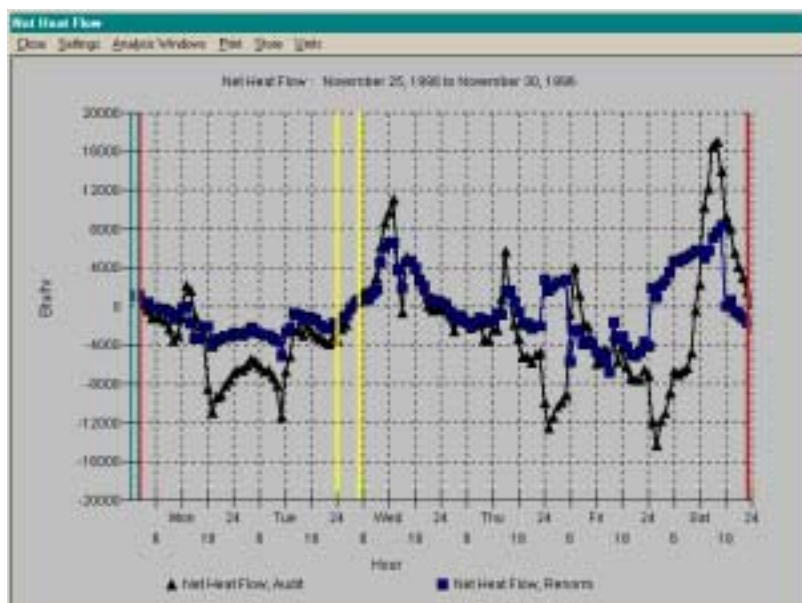
Figure 16. STEM heat flow graph

The blower door test showed the ELA to be 62 in^2 using the power-law curve fit of pressure difference versus air-flow (see Figure 17). The corresponding ACH level (derived in Appendix J) is 0.2 ACH. The low ELA and ACH means that the infiltration term is not a significant source of error in the PSTAR process used in the STEM 2.0 software.
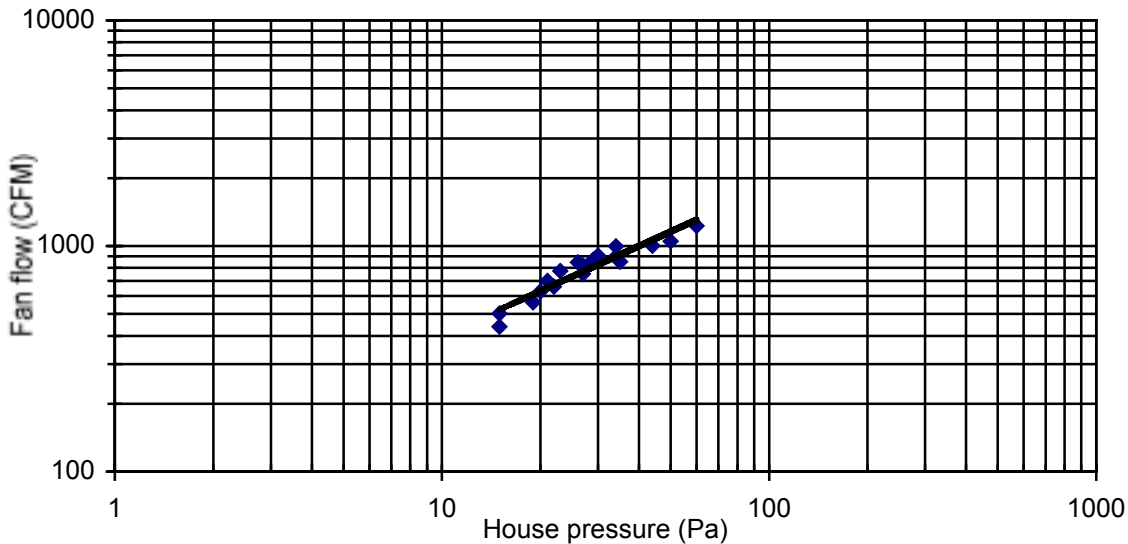
Figure 17. ELA power law curve fit

The first primary heat flow renormalized by the STEM 2.0 program was the building conductive gain to room air from outside air under measured under steady-state conditions, which is calculated as building load coefficients (BLC) times the inside-outside temperature difference. Renormalizing is accomplished by multiplying the heat flow by a weighting factor, which results from using the PSTAR method [15,16,18]. The preliminary BLC obtained from the building envelope properties of the as-built model was 496 Btu/hr·°F (261 W/°C) including 46 Btu/hr·°F (24 W/°C) caused by infiltration. This compares to 357 Btu/h·°F (203 W/°C) when calculated manually, without including infiltration, as shown in Appendix E. The renormalizing factor was 0.99, resulting in an adjusted BLC of 446 Btu/h·°F (235 W/°C), not including the infiltration.

The second primary term renormalized is the heat flow to the room air that results from changes in inside air temperatures, which relates to the effective capacity of the house to store heat. The value predicted from the audit model was adjusted by a factor of 0.40, resulting in an effective building heat capacity of 113,651 Btu/°F (215,824 kJ/°C).

The last term renormalized was the heat flow to the inside air caused by solar gain. This heat flow refers to solar gains through windows, heat stored in building mass that gets discharged into the inside air and heat flow through external walls caused by solar absorption. This effective solar gain was shown to be 73% of the value predicted by the audit model.

4.8 Long-Term Data Analysis

Even though the data logger was installed earlier, complete sets of continuous long-term data are only available from November 18, 1996, through October 14, 1997, because of data collection problems. During this period, the house was unoccupied. Heating was provided only during the STEM testing

period, which prevents proper comparison with STEM results or with long-term predictions of the computer models. Additionally there was no natural ventilation, which is an integral part of the house's cooling energy performance. However, the data are useful for observing the temperature stabilizing performance of the building as seen in Figure 18, which shows the hourly indoor and outdoor temperatures from November 1996 to October 1997.
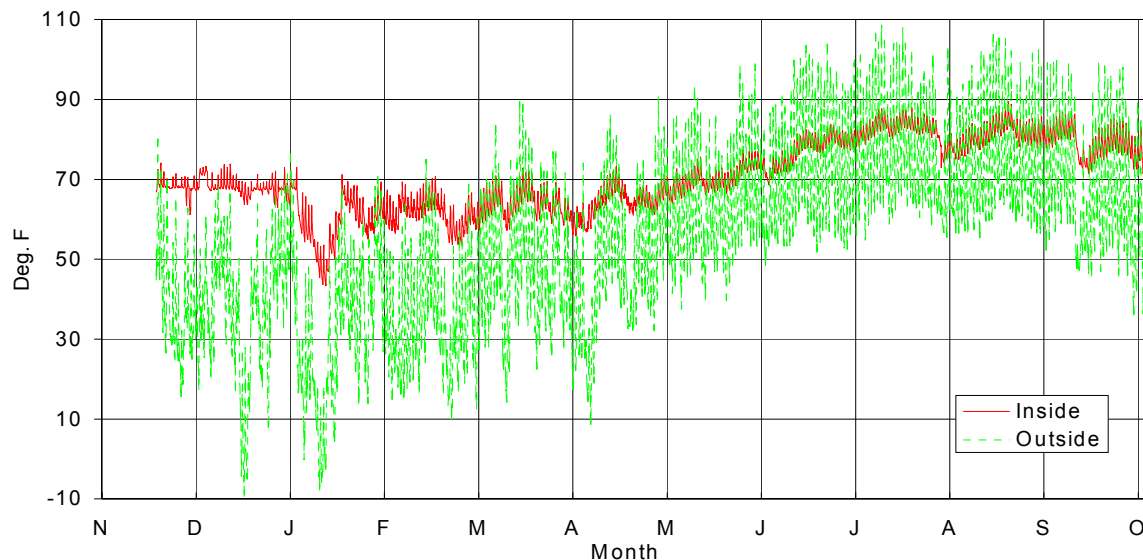
Figure 18. November to October indoor and outdoor temperature profiles

Figure 19 shows the January temperature profile when the coldest indoor temperatures occur. The temperature never drops below 40°F (4.4ºC) even though outdoor temperatures were below freezing for a large part of the month, including several sub-zero (-18ºC) days. These temperatures were maintained without any heating or significant internal gains, indicating that the temperature inside the house is unlikely to ever drop below freezing. This makes the passive solar design very resistant to disasters where infrastructure is disabled.
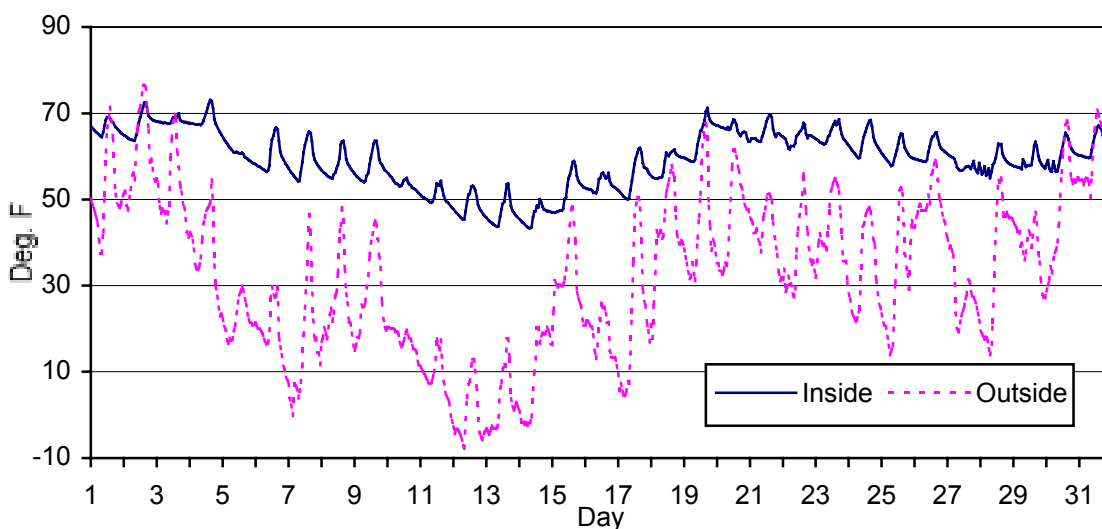
Figure 19. January hourly inside and outside temperatures

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The ability of the house to stay cool without air-conditioning is only partly evident from the long-term data. During July, the house maintained an 80°–85°F (26.7°–29.4ºC) indoor temperature range with outside temperatures of more than 100°F (37.8ºC) (see Figure 20). This range is above the acceptable ASHRAE comfort range [20] by only a few degrees. Because there were no occupants during the monitoring period, natural ventilation did not occur. The low nightly temperatures indicate that the house could benefit from venting. The house is designed to get its cooling from the night venting, which would reduce the internal temperatures to an acceptable level. Simulation results using the calibrated model with proper venting show that the house would remain below 78°F (within the comfort range for this climate) during July, the hottest month of the year (see Figure 21). Cooling loads are insignificant and with good design, air-conditioning is not necessary to maintain thermal comfort in this climate.
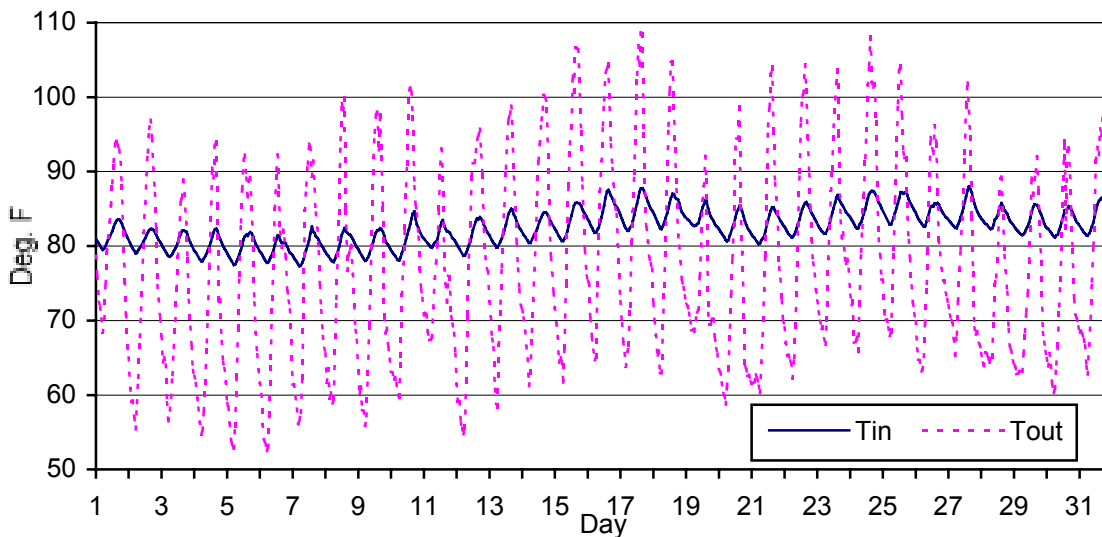
Figure 20. July temperature profiles
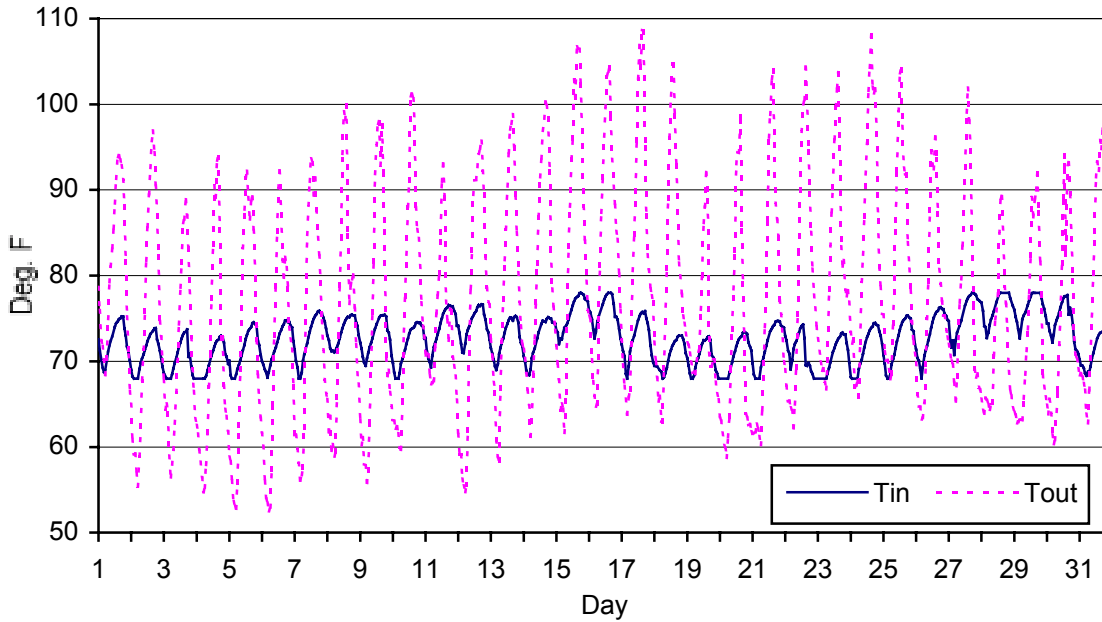
Figure 21. Predicted indoor temperatures with night venting

Figures 22 and 23 show the individual indoor temperature channels plotted together for January and July. There are slight variations in temperature throughout the house. The data show that the heat from solar gains is well distributed with no single room displaying a tendency to heat up more than another. This indicates that the natural convection does a good job of mixing the air in the house.
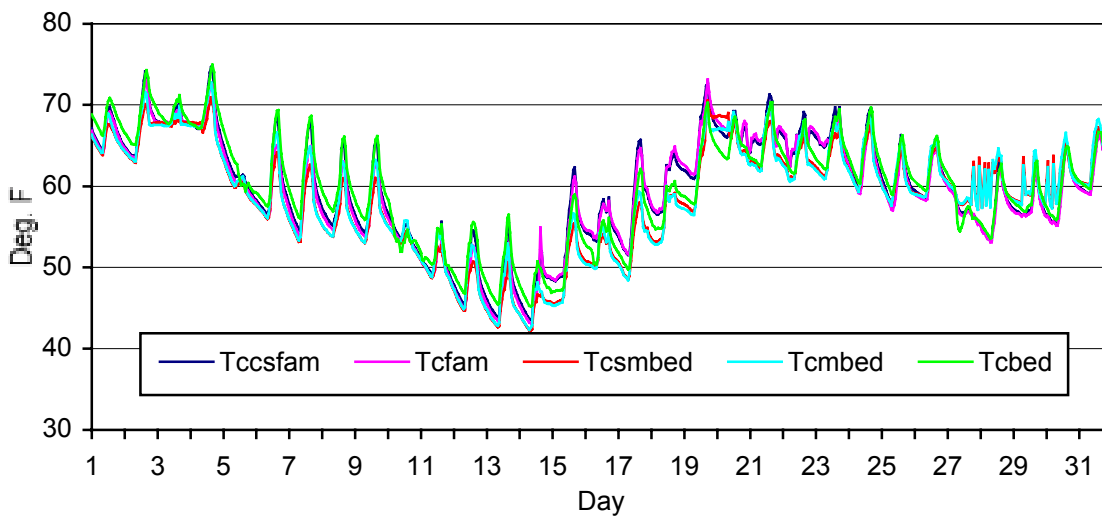
Figure 22. Individual indoor temperature profiles for January

23
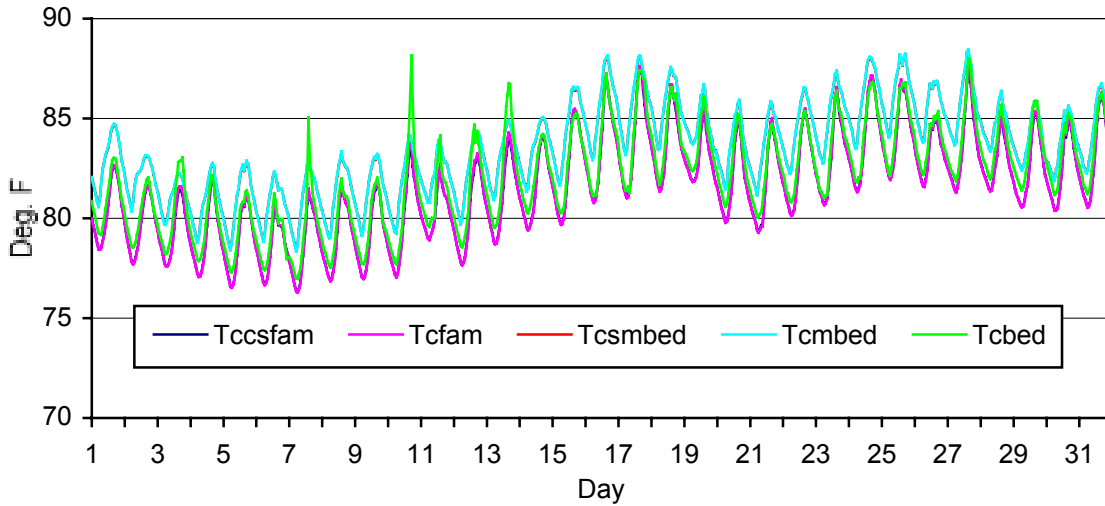
Figure 23. Individual indoor temperature profiles for July

Researchers anticipated that the house would be sold, and that long-term data could be used to study the occupant interaction with the low-energy home. The house was on the market for the entire time data was being collected. When the house finally sold, the owners did not want data collection to continue.

4.9 Infrared Analysis

Infrared imaging identifies problem areas in the building envelope such as insufficient insulation levels or thermal bridging by measuring surface temperatures. Cooler surfaces show up as greens and blues, and warmer surfaces show up in reds and yellows. Infrared pictures of the inside and outside of Tierra I were taken to identify areas of poor thermal performance.

According to the infrared images, the roof insulation appears adequate (see Figures 24 and 25) because the roof shows up as cool (light blue). The walls appear much warmer (red and orange), indicating the insulation levels are not as good. This is especially evident in Figure 26 and backs up the STEM conclusions that the BLC is too low in the as-built model. These observations agree with the results of the calibrated model, which indicate a high level of heat loss from the walls compared to the loss from the ceiling.
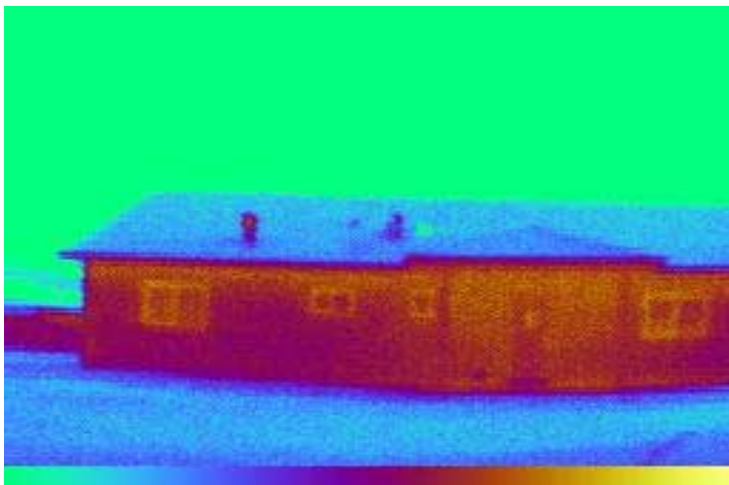
Figure 24. Infrared image of north side of house
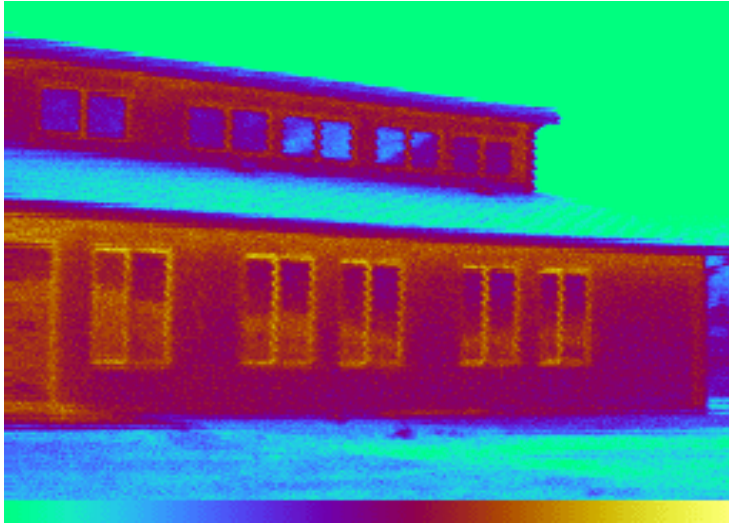
Figure 25. Infrared image of south side of house
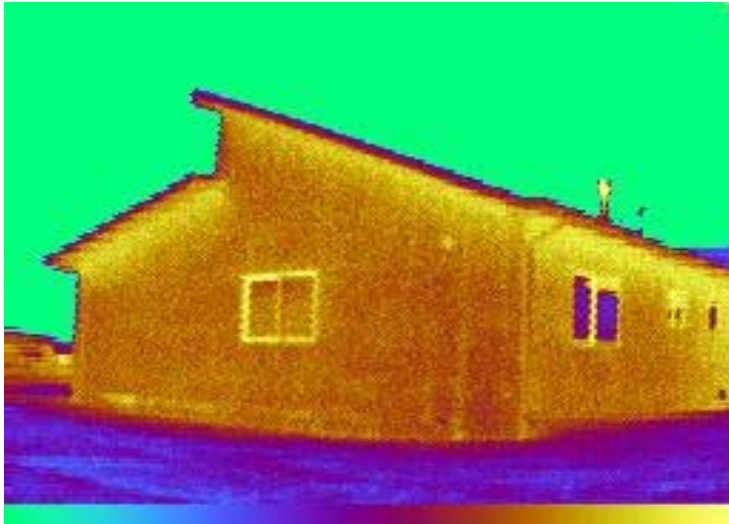
Figure 26. Infrared image of east side of the house

On the inside of the house, infrared images showed some thermal bridging in the ceilings where the rafters are located. The thermal bridges show up as cool (blue) streaks in the ceiling (see Figure 27). Poor thermal performance in the corners and along the edges where the walls and ceiling meet is also evident as indicated by very cool (green) patches in those areas. Insulation must be applied to the edges of the ceiling to the specified level.
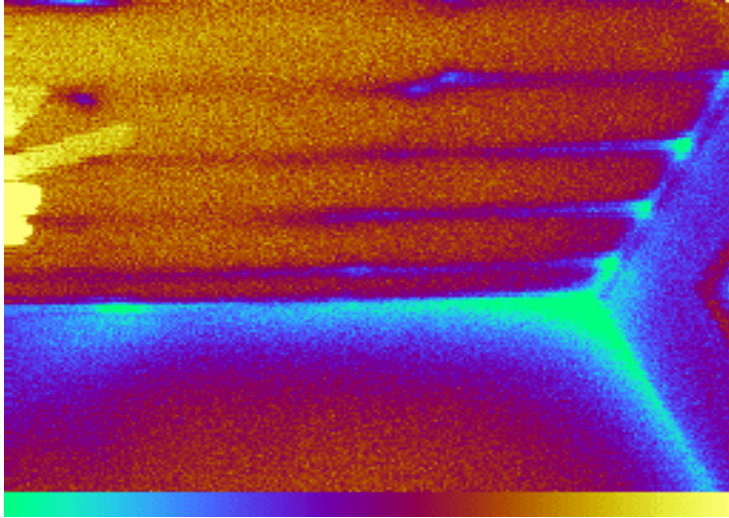
Figure 27. Thermal bridging at ceiling corner

There is also a problem with thermal bridging where the stove exhaust penetrates the ceiling, as evidenced by a green and blue patch in that area (see Figure 28). This is probably from a gap in the insulation. It appears to be the same level of thermal bridging as that found along the window frames, which is the same color. The heat loss from these areas may be reduced with better caulking and improved window frames. Care must be taken to seal all penetrations.
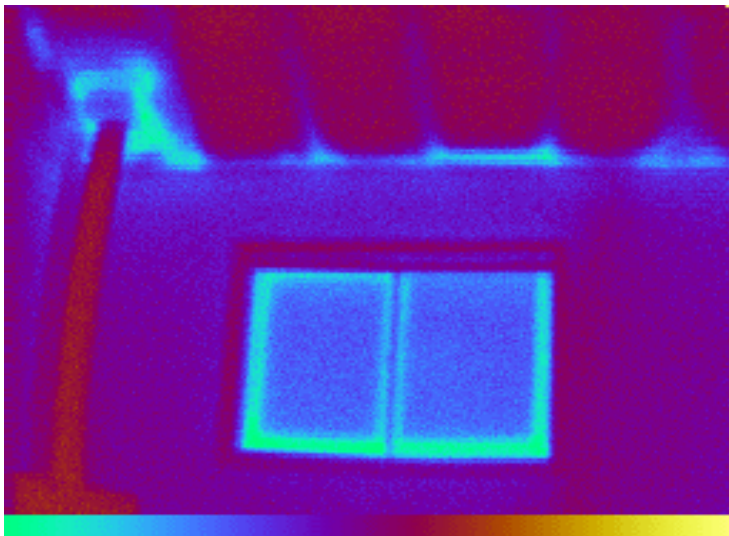
Figure 28. Thermal bridging at roof penetration of chimney and at window frame

Chapter 5 - Analysis, Recommendations, and Conclusions

5.1 Overall Performance Issues

Tierra I performance is 56% better than the HERS/MEC base case, but it did not achieve the 70% savings goal. The thermal mass of the house worked as expected in reducing the temperature swings, and the airtight construction was effective in reducing infiltration. However, there was less solar gain than expected from preliminary modeling. Because additional solar gain was anticipated, the level of insulation was reduced to match the anticipated gains with the losses.

5.2 Glazing Issues

Solar gain problems were identified primarily through the STEM results, which indicated the effective solar gains of Tierra I were only 73% of the predicted value. Because Tierra I relies on passive solar gain as the primary source of heating, it is important to understand what caused the large discrepancy. The problem could come from incorrect glazing models, poorly performing windows, or extrapolating vertical insolation from measured horizontal data. Underestimating the effect of shading from mullions, screens, and other obstructions also affects the results.

The first area examined for possible discrepancy was the glazing model used for estimating the solar gains. The STEM test results, which showed the over-prediction in solar gains, are based on the SERI-RES thermal simulation engine. SERI-RES predicts solar gains of 59.7 MMBtu (17.5 MW·hr), while SUNREL, which has an improved diffuse shading model [21] and can use WINDOW 4.1 glazing description files, predicts solar gains of only 49.7 MMBtu per year (14.6 MW·hr) with the same house description. The SUNREL model predictions are closer to the actual results. The STEM software cannot account for this 17% drop in estimated solar gains because it uses the SERI-RES model.

Additional overestimation may result from having derived the beam and diffuse radiation falling on the vertical plane from radiation measured on a horizontal plane. These models make assumptions about ground reflectivity and the diffuse nature of the sky. Measured data was not available to determine the effect on the building model. Future efforts should use multiple pyranometers to determine the radiation values.

It is also important to determine whether the performance of the low-E windows meets manufacturers' specifications and the consequential effects on the actual house. Such an analysis is beyond the scope of this report. Methods of testing windows in the whole building are needed to quantify this information. Future work in this area should help provide better initial energy-use estimates so that better optimization can be performed.

The last glazing issue related to modeling is to better estimate the window parameters, including area and shading effects, during the design phase. The sensitivity to solar gains on the performance is large; therefore, window characteristics have a large effect on total performance. The effect of the mullions is 3-dimensional and cannot be considered an opaque 2-D surface. The screens alter the shading coefficient of the glass as well as the boundary layer.

With tighter construction and higher insulation levels, passive solar gains contribute to a larger percentage of the heating loads of passive solar homes. This requires glazing systems to be modeled more accurately to better predict performance.

5.3 Ground Issues

The other major modeling problem area identified was the ground heat loss. Tierra I was constructed with perimeter insulation (see Figure 29) but without insulation under the slab. The calibrated model showed that ground heat loss accounted for 37% of the total heat loss, indicating that the slab should be insulated. With this estimated level of heat loss, variations in the ground model can substantially change the building performance estimates. Proper models are needed to determine recommended insulation levels.
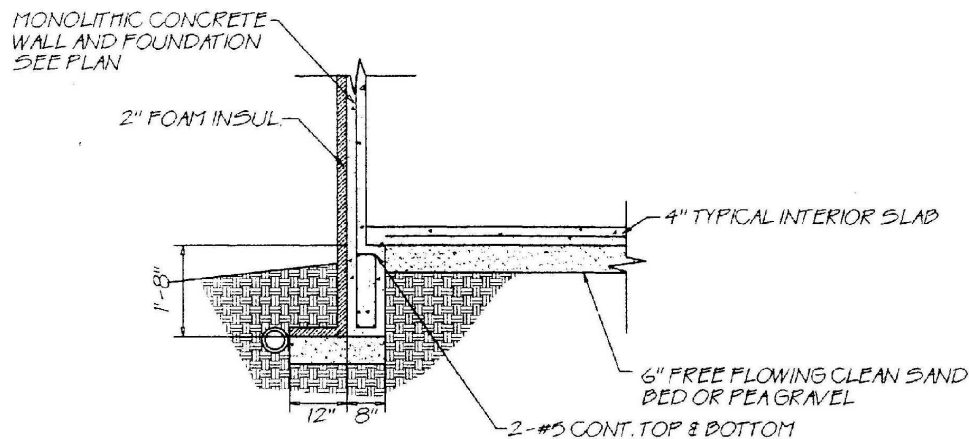
Figure 29. Foundation insulation detail

Ground loss is simulated with two separate slab sections in the SUNREL model (Figure 30). The first section represents the insulated perimeter. It is modeled as a concrete layer with an insulation layer and 1.5 ft (0.46 m) of dirt connected to the ambient node. The area of this section is the equivalent of a 4 ft (1.22 m) wide strip around the edge of the slab. The second section is modeled as a concrete layer with 4.5 ft (1.4 m) of dirt between it and the ground node. This model, based on ASHRAE models [20], is one-dimensional even though ground loss is a three-dimensional effect.
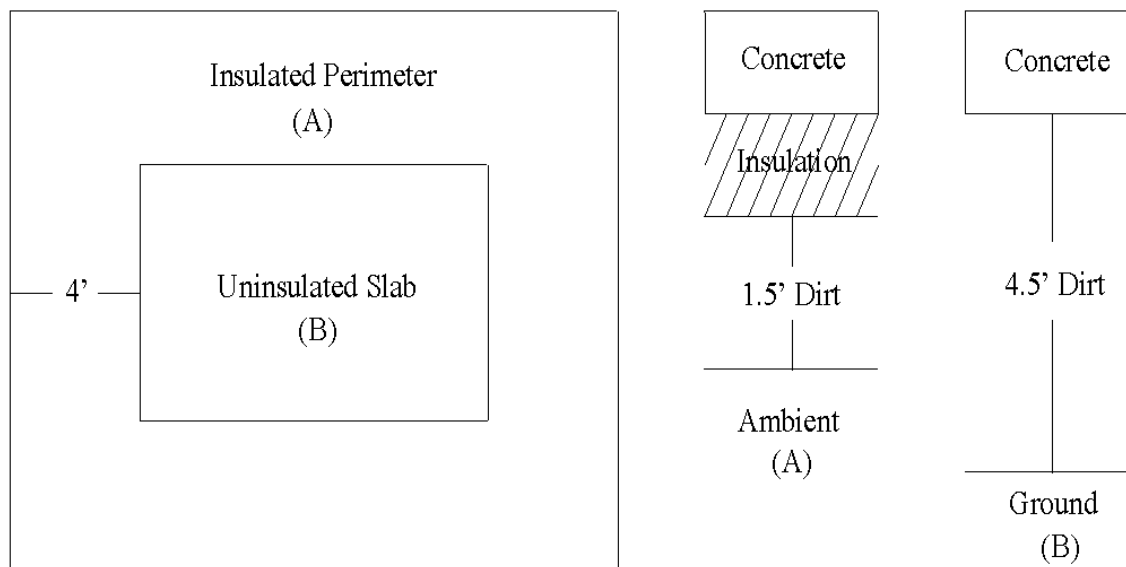
Figure 30. Diagram of ground loss model

There is no data with which to determine the accuracy of the model because ground-heat loss was not measured for Tierra I. Future projects should measure ground-heat flow data to determine the accuracy of the ground models and to verify the predicted percentages of total heat loss.

5.4 Design Improvement Based on Lessons Learned

Changes to the design were made to see if a 70% saving could be obtained while assuming the lower effective glazing SC as determined in Section 3.8. Results from the thermal analysis and model calibration indicated significant improvements would result from increased insulation for the walls and floor. The wall insulation was increased from 2 inches to 3 inches of polyisocyanurate (R-21 ft²·°F·hr/Btu [10.1 m²·K/W]) and 2 inches of foam insulation (R-10 ft²·°F·hr/Btu [4.8 m²·K/W]) were added under the entire slab. That was sufficient to achieve the 70% savings goal.

5.5 Improved Design Results

The improved design has a total heating load of 14.72 MMBtu (4.31 MW·hr) per year and a cooling load of 0.28 MMBtu (82.1 kW·hr) per year, which is 70.4% less than the base case. Heat-loss breakdown for the improved design is shown in Figure 31. The two largest heat losses are through the windows and floor. Window heat loss can be reduced by using windows with lower U-values; however, this comes with a trade off because windows with lower U-values often have lower solar gains. The ground-heat loss could be reduced by increasing insulation levels, but this might not be practical or necessary. Improved ground-loss modeling will help give a better estimate of ground-heat loss contribution, as well as optimal insulation levels.
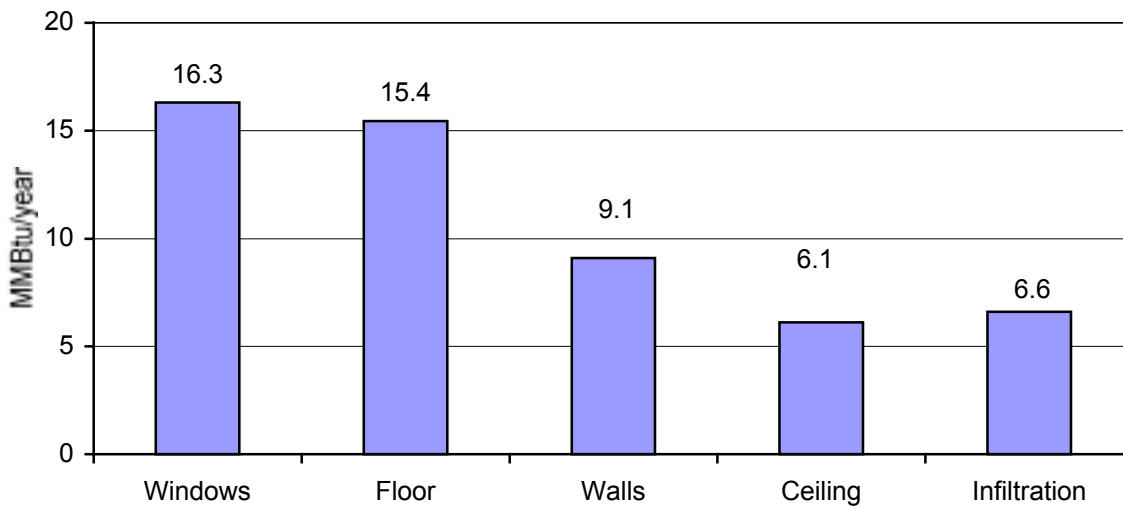
Figure 31. Breakdown of heat loss in improved design model

5.6 Lessons Learned

Several important lessons were learned as a result of this study:

1. Scaling up the design does not result in the same energy savings percentages. The savings predicted for the smaller design was 94% [4] while the predicted savings for the larger design was only 70% (56% actual) (see section 3.7).
2. Improved ground-loss models are needed. Ground loss plays a significant role in the total heat loss compared to the rest of the thermal envelope. This heat loss needs to be characterized better to enable us to make more accurate predictions of ground loss and to determine the appropriate perimeter and slab insulation levels.
3. Insulation under the slab is needed. Modeling of the improved design showed that insulating all parts of the slab and not just the perimeter helped achieve desired savings.
4. The glazing needs to be modeled better. The glazing models have improved, but a better method needs to be implemented for entering correct window characteristics, including mullions and screens.
5. The need for mechanical cooling in some climates can be eliminated with proper design. Without night venting, the indoor temperature was only a few degrees above the thermal comfort zone, and modeling showed that the temperatures would remain within the comfort zone if proper venting was used.
6. Movable shading is useful in reducing cooling loads even with fixed overhangs because of diffuse radiation [22]. It is possible to replace all overhang shading with movable shading for optimal heating and cooling loads; however, overhangs work independent of occupant behavior and can be sized for a minimal impact to the heating load.

5.7 Final Recommendations

Future houses should be designed and engineered based on actual floor area. The size of the model influences the volume-to-outside-surface-area ratio, which influences optimal window area and insulation levels. The size also affects the perimeter-to-floor-area ratio, resulting in differing ground insulation level recommendations. Scaling is not effective in passive solar design.

The low-energy passive solar building depends heavily on solar gains, so it is important to get the glazing area in the model correct to obtain a good estimate of the heating loads. It was noted in section 5.2 that the new SUNREL model gives a more accurate estimate for solar gains. Therefore, SUNREL modeling should replace SERI-RES modeling.

Results from the STEM test, infrared imaging, and modeling indicated a need for increased insulation levels. Wall insulation should be increased to 3 inches of polyisocyanurate (R-21 ft²·°F·hr/Btu [10.1 m²·K/W]). A minimum of 2 inches of insulation (R-10 ft²·°F·hr/Btu [4.8 m²·K/W]) should be added under the entire slab to reduce the ground heat loss during the heating season. Additional care should also be taken to reduce the heat loss, visible in the infrared images, between the roof and the top of the walls.

5.8 Future Work

Work needs to be done in the following areas:

1. Update the STEM 2.0 software to use the SUNREL routines as well as DOE 2.x and other simulation tools.
2. Improve ground-loss models.
3. Improve the SUNREL glazing section so window characteristics are more easily entered into the model.

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Appendix A—The STEM/PSTAR Method

The STEM/PSTAR test method has been used successfully on more than 100 residential buildings and 6 commercial buildings. The term STEM refers to the test itself and the subsequent analysis. PSTAR refers to the mathematical formalism used to separate building energy flows into convenient segments [19]. The method provides a means of separating effects that tend to be mixed together in the monitored data from a building. This separation allows the user to identify the three primary thermal characteristics of the building: (1) the BLC, (2) the effective building mass, and (3) the effective solar gain area. An adjusted model can then be used to predict future building performance. The PSTAR method minimizes cross talk between the three characteristics; an important advantage.

An approximate thermal simulation model for the building is developed based on a quick audit of the plans. NREL uses the SERI-RES simulation program, although, in principle, one could use any simulator. The advantage of starting with a detailed simulation model of the building (instead of taking a black-box approach) is that known building characteristics amenable to direct observation are imbedded in the model. Of primary importance is the distribution of primary mass elements and the size, orientation, and shading of all windows. The former allows one to predict an appropriate mix of fast and slow dynamic responses, and the latter allows data from a short-term test carried out during one season to be used to predict performance in another season, even though sun angles may be quite different. Accurate modeling of other details, such as thermal bridges and the effectiveness of insulation, is not as important because BLC will subsequently be renormalized.

In the PSTAR procedure, the heat flow into the room air is mathematically separated into nine terms relating to the effect causing the heat flow. This disaggregation of terms is unusual, but is central to the PSTAR method. During the test, these are the only terms considered. Therefore, if energy is to be balanced, the sum of the nine terms should be equal to zero at each hour. The sum is called Q_{net} and is calculated as an hourly data stream throughout the test. Non-zero values of Q_{net} indicate the inability of the model to balance energy at that particular hour.

In a typical application, three of the major energy-flow terms are determined. This is accomplished by multiplying each of these terms by a constant re-normalization factor. The constants are chosen to force the average value of Q_{net} to zero during carefully chosen periods of the test. The re-normalization is done in three steps.

Step one is performed during a period of 2 to 4 hours at the end of a night when the inside temperature has remained reasonably steady (this is called the co-heating period). The dominant terms during this period are the heat input from the electric heaters and the heat losses by conduction and infiltration. Heat storage, solar, and other effects are small but not negligible. The steady-state conduction term is multiplied by the re-normalization factor to achieve an exact energy balance for the co-heating period.
Steps two and three are similar. The energy-flow term caused by discharge of building mass is dominant during the cool-down period. The solar-gain term is usually large during the daytime hours. Re-normalization factors for these terms are determined based on the whole data period.

The three steps are repeated until the re-normalization constants stabilize. If the model is reasonably accurate, Q_{net} should be small throughout the test period. Root-mean-square values of Q_{net} for residential tests have typically been in the range of 100 Btu/hr (29 W) at night and 1700 Btu/hr (498 W) during the day.

A validation of the STEM method has shown that averaged results from repeated STEM tests can detect differences in the BLC in the 5% range and STEM is effective at determining changes in thermal mass [23].

Appendix B—Heat Gain Ratios

Solar Heat Gain Coefficient (SHGC)

The SHGC is the fraction of incident irradiance that enters through the glazing as heat gain. A window with no glass would have a SHGC of 1.00.

Shading Coefficient (SC)

The SC is the ratio of solar gain of the window to that of a reference piece of glass. Typically, this reference is a standard reference window of single-pane, double-strength, clear glass. Therefore,

$$SC = \frac{SHGC_{test}}{SHGC_{ref}} \text{ [20]},$$

where $SHGC_{ref}$ = 0.86 for single-pane, double-strength, clear glass. Product literature typically uses this value for comparison purposes.

Shading Factor (SF)

The term SF, used by SUNREL and SERI-RES, is the ratio of solar gain of the window to that of an n-pane, double-strength, clear glass, where n is the same for both the reference and test sample.

$$SF = \frac{SC}{SC_{clear}},$$

where SC_{clear} is 0.89 for double-pane glass.

Examples:

Glass Type	SHGC	SC	SF
Single-pane – clear	0.86	1.00	1.00
Double-pane – clear	0.77	0.89	1.00
Triple-pane – clear	0.65	0.76	1.00
Double-pane – low-E	0.55	0.64	0.72

Note: Many low-E combinations are available.

Appendix C—HERS/MEC Base Case Calculations

The base-case house conforms to the HERS Guidelines [2] guideline #13 and the 1995 Model Energy Code [1].

Building geometry as specified by HERS A.1 and A.2:

- Length = 62.33 ft
- Width = 30 ft
- Height = 8 ft
- Floor area = 1,870 ft^2
- Window area = 337 ft^2 (HERS A.6) including 27% framing (HERS A.9)
- Area doors = 40 ft^2 (HERS B.3)

Building insulation levels:

- U_o = 0.14 Btu/hr·ft^2·°F (0.24 W/m^2·K) (MEC Chapter 5, Section 502.2)
- U_w = 0.058 Btu/hr·ft^2·°F (0.1004 W/m^2·K) (HERS Table 6a)
- U_f = 0.40 Btu/hr·ft^2·°F (0.69 W/m^2·K) (HERS section A.3.c)
- U_d = 0.20 Btu/hr·ft^2·°F (0.34 W/m^2·K) (HERS B.3)
- U_r = 0.028 Btu/hr·ft^2·°F (0.048 W/m^2·K) (MEC Chapter 8, Figure 2)
- R_{slab} = 4.4 hr·ft^2·°F/Btu (2.5 m^2·K/W) (MEC Chapter 8, Figure 3)

U_o : U value for gross wall area
U_w : U value for opaque wall area including framing
U_f : U value for glazing area
U_d: U value for doors
U_r : U value for ceiling/roof
R_{slab} : Foundation/perimeter insulation

Additional specifications:

- Slab-on-grade as specified by HERS A.4
- 0.67 ACH (Air Changes per Hour) (HERS B.1)
- SC = 0.7 during cooling season and 0.89 during heating season from HERS B.2
- Wall solar absorptivity = 0.50 from HERS A.5
- Roof solar absorptivity = 0.75 from HERS A.5
- Internal mass = 8 lbs/ft^2 (39 kg/m^2) from HERS B.4

The SUNREL building description file for the HERS/MEC base case house is located in Appendix F.

Appendix D—Sensible and Latent Gain Schedules

Table D1. Sensible and Latent Gain Sources

Source	Number	Sensible Btu/hr	Latent Btu/hr	Hr/day
Lights	8	136	0	6
Refrigerator	1	389	0	24
People-day	3	230	190	6
People-night	3	161	133	8

Table D2. Sensible and Latent Schedules

Hr	Lights (Btu/hr)	Cooking (Btu/hr)	Refrigerator (Btu/hr)	People (Btu/hr)	Total Sensible (kBtu/hr)	People (Btu/hr)	Total Latent (kBtu/hr)
1			389	483	0.872	399	0.399
2			389	483	0.872	399	0.399
3			389	483	0.872	399	0.399
4			389	483	0.872	399	0.399
5			389	483	0.872	399	0.399
6	1088	1500	389	690	3.667	570	0.570
7	1088	1500	389	690	3.667	570	0.570
8			389		0.389		
9			389		0.389		
10			389		0.389		
11			389		0.389		
12			389		0.389		
13			389		0.389		
14			389		0.389		
15			389		0.389		
16			389		0.389		
17			389		0.389		
18	1088	1500	389	690	3.667	570	0.570
19	1088	1500	389	690	3.667	570	0.570
20	1088	1500	389	690	3.667	570	0.570
21	1088	1500	389	690	3.667	570	0.570
22			389	483	0.872	399	0.399
23			389	483	0.872	399	0.399
24			389	483	0.872	399	0.399

Appendix E—Manual UA Product Calculations

Table E1. UA Product for Individual Components and the Whole Building

Envelope Heat Loss	Area (ft^2)	U-value (Btu/hr·ft^2·°F)	UA (Btu/hr·°F)
Ceiling/Roof			
Roof	2150	0.0230	54.13
Walls			
North	419	0.0828	37.00
South	343	0.0828	29.72
East	223	0.0817	18.46
West	240	0.0817	19.61
Clerestory	126	0.0526	6.63
Windows			
Glazing	269	0.3600	96.84
Framing	103	0.2000	20.68
Conduction above ground		**Sub-total**	283.07
Foundation Heat Loss	Perimeter	F2 - Factor *	
Slab	186	0.4	74.40
		Total	357.47

* - From ASHRAE Fundamentals, 1993.

Appendix F—SUNREL Building Description Files

<u>HERS/MEC Model</u>
```
Tierra I Base Case Model.
This model is designed to conform to HERS/MEC 93 specifications.
It is to be used to give an estimate of energy savings for the actual
house designed and built at 1134 West McCulloch, Pueblo CO.
Window area is 18% of 1870sqft; window framing is 27% of that.


Created by: Michael Smith
Created on: 7/1/98 11:13:23 AM
Last modified by: Michael Smith
Last modified on: 2/24/00 4:04:08 PM

&RUNS
LABEL = 'run1'
STATION = 'pueblo'
RSTRTMN = 'JAN'
RSTOPMN = 'DEC'
RUNITS = 'E'
DDTYPE = 'US'
GREFL = 0.3
GTEMP = 55
RSTRTDY = 01
RSTOPDY = 31
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&ZONES
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LATSCD = 'L-GAIN-M'
ZAREA = 1870
ZHGT = 9.333
ZACH = 0.67
SOL2AIR = 0.2
SOLLOST = 0.05
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&INTERZONES
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&WALLS
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'slab-ins',  'roof',  'roof',  'door'
WFRNTZONE = 'main',  'main',  'main',  'main',  'main',  'main',  'main',
'main',  'main'
WBACKZONE = 'south-wall',  'east-wall',  'north-wall',  'west-wall',
'GROUND',  'AMBIENT',  'roof-south',  'roof-north',  'north'
WALLHGT = 8.0, 8.0, 8.0, 8.0, 62.33, 62.33, 15.0, 18.0, 8.0
WALLONG = 62.33, 30.0, 57.33, 30.0, 18, 12, 62.33, 62.33, 5
WFRNTH = 1.46, 1.46, 1.46, 1.46, 1.2, 1.2, 1.3, 1.3, 1.46
WFSOLABS = -999, -999, -999, -999,.32, .18,  -999, -999, -999
WBACKH = 5.11, 5.11, 5.11, 5.11, 3, 3, 3, 3, 5.11
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WBSOLABS = 0.5, 0.5, 0.5, 0.5, 0, 0, 0.75, 0.75, 0.5
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WINZONE = 'main',  'main',  'main',  'main'
WEXTSURF = 'south-wall',  'north-wall',  'east-wall',  'west-wall'
GLAZTYPE = 'double',  'double',  'double',  'double'
WINHGT = 4, 4, 4, 4
WINLONG = 21, 21, 21, 21
WINX = 20.666, 20.666, 4.5, 4.5
WINY = 3, 3, 3, 3
FRAMEPCNT = 27, 27, 27, 27
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&TROMBEWALLS
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&SURFACES
NAMESURF = 'north-wall',  'east-wall',  'south-wall',  'west-wall',  'roof-
south',  'roof-north',  'north'
SURFAZIM = 0, 90, 180, 270, 180, 0, 0
SURFTILT = 90, 90, 90, 90, 21, 21, 90
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&HVACTYPES
HVACZONE = 'main'
HSETSCD = 'heat1'
VSETSCD = 'vent1'
CSETSCD = 'cool1'
VENTRATE = 5
COILTEMP = 55
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&FANS
/

&ROCKBINS
/

&NATURALVENT
/

&TROMBETYPES
/

&WALLTYPES
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'intwall'
WALLAYER(1,1) =  'R-17.2'
WALLAYER(1,2) =  'concrete', 'dirt', 'dirt', 'dirt'
WALLAYER(1,3) =  'concrete', 'R-4.5', 'dirt'
WALLAYER(1,4) =  'R-35.2'
WALLAYER(1,5) =  'pine'
WALLAYER(1,6) =  'R-2.5'
WALLAYER(1,7) =  'drywall', 'R-1', 'drywall'
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NAMEMASSTYPE = 'pine',  'drywall',  'concrete',  'dirt'
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MASSDENS = 27, 50, 150, 95
MASSCP = 0.29, 0.26, 0.16, 0.2
MASSTHICK = 0.3333, 0.0417, 0.5, 1.5
MASSNODES = 1, 1, 4, 8
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&PCMTYPES
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&GLAZINGTYPES
NAMEGLZTYPE = 'double'
SHDFACTSCD = 'var'
UGLAZ = 0.4
GEXTINCT = 0.5
REFINDEX = 1.526
GLZTHICK = 0.125
NGLAY = 2
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&ROCKBINTYPES
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&FANTYPES
/

&OVERHANGTYPES
/

&SIDEFINTYPES
/

&SKYLINETYPES
/

&SCHEDULES
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'var',  'var',  'I-GAIN-M',  'L-GAIN-M',  'ground',  'ground',  'ground',
'ground',  'ground',  'ground',  'ground',  'ground',  'ground',  'ground',
'ground',  'ground'
SCHDSEASON = 'winter',  'winter',  'winter',  'summer',  'summer',  'summer',
'summer',  'winter',  'YEAR',  'YEAR',  'Mar',  'Apr',  'May',  'Jun',
'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec',  'Jan',  'Feb'
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SCHDL(1,8) = 0.9, 0.9, 0.9, 0.9, 0.9, 0.9, 0.9, 0.9, 0.9, 0.9, 0.9, 0.9, 0.9,
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SCHDL(1,9) = 0.872, 0.872, 0.872, 0.872, 0.872, 3.668, 3.668, 0.389, 0.389,
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40.5
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OUTUNITS = 'E',  'E',  'E'
OUTSEASON = 'winter',  'winter',  'YEAR'
FRMT = 'Y',  'Y',  'Y'
IOCOMP = 1,  -999,1
IOPAGE = -999, -999, -999
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NAMESEASON = 'YEAR',  'winter',  'summer',  'Jan',  'Feb',  'Mar',  'Apr',
'May',  'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
SEASTRTMN = 'JAN',  'OCT',  'MAY',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
SEASTOPMN = 'DEC',  'APR',  'SEP',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
DAYOFWEEK = 'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',
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SEASTOPDY = 31, 30, 30, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31
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&STATIONS
NAMESTATION = 'pueblo'
WEATHERFILE = 'C:\Program Files\SUNREL\library\weatherfiles\pueblo.tmy'
WEATYPE = 'TMY'
WSTRTMN = 'JAN'
WSTOPMN = 'DEC'
SITELAT = 38.18
SITELONG = 104.3
ELEV = 4641
TERRAIN = 2
SHIELD = 1
WSTRTDY = 01
WSTOPDY = 31
/

&PARAMETERS
/
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Preconstruction Model
This is an 1,870 ft^2 house built by Tierra Concrete Homes in 1996 at 1134
West McCulloch, in Pueblo CO.
The description is based on construction plans.

Created by: Michael Smith
Created on: 7/1/98 11:13:23 AM
Last modified by: Michael Smith
Last modified on: 2/23/00 3:50:27 PM

&RUNS
LABEL = 'Run1'
STATION = 'pueblo'
RSTRTMN = 'JAN'
RSTOPMN = 'DEC'
RUNITS = 'E'
DDTYPE = 'US'
GREFL = 0.3
GTEMP = 55
RSTRTDY = 01
RSTOPDY = 31
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SENSSCD = 'I-GAIN-M'
LATSCD = 'L-GAIN-M'
ZAREA = 1870, 473, 748
ZHGT = 9.333, 8, 2
ZONEZ = , , 8
ZACH = 0.25, 4.00, 4.00
SOL2AIR = 0.2, 0.2, 0.0
SOLLOST = 0.05, 0.05, 0.00
GAINSENS = , 0.000, 0.0
GAINLAT = , 0.000, 0.0
/

&INTERZONES
/

&WALLS
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'concrete6', 'concrete6', 'extframe', 'ceiling', 'extframe', 'roof-att',
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WFRNTZONE = 'main', 'main', 'main', 'main', 'main', 'garage', 'main',
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'garage', 'garage', 'garage', 'garage', 'garage', 'garage', 'garage',
'main', 'main', 'main', 'main'
WBACKZONE = 'north-wall', 'east-wall', 'south-wall', 'west-wall',
'garage', 'east', 'south-clr', 'attic', 'attic', 'roof-south', 'roof-
north', 'GROUND', 'AMBIENT', 'main', 'main', 'south', 'west', 'north',
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'south-wall', 'south-clr'

44

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WALLHGT = 8.0, 8.0, 8.0, 8.0, 8.0, 8.0, 4.0, 12.0, 4.0, 15.0, 18.0, 19.0,
11.0, 8.0, 8.0, 8.0, 8.0, 8.0, 18, 8, 22, 8.0, 8.0, 8.0, 8.0, 4.0
WALLONG = 62.33, 30.0, 62.33, 12, 18, 4, 62.33, 62.33, 62.33, 62.33, 62.33,
62.33, 62.33, 160, 20.0, 21.5, 22.0, 21.5, 17.5, 19.75, 22, 21.5, 62.33, 30,
62.33, 62.33
WALLPERCENT = 93, 98, 94, , , , 88, , , , , , , , , , , 43, , , , 57, 7, 2,
6, 12
WFRNTH = 1.46, 1.46, 1.46, 1.46, 1.46, 1.46, 1.46, 1.3, 1.46, 1.3, 1.3, 1.2,
1.2, 1.46, 1.46, 1.46, 1.46, 1.46, 1.2, 1.2, 1.3, 1.46, 1.46, 1.46, 1.46,
1.46
WFSOLABS = -999, -999, -999, -999, -999, -999, -999, -999, -999, -999, -
999,.32, .18,  -999, -999, -999, -999, -999, -999, -999, -999, -999, -999, -
999, -999, -999
WBACKH = 5.11, 5.11, 5.11, 5.11, 1.46, 5.11, 5.11, 1.2, 1.46, 3, 3, 3, 3,
1.46, 1.46, 5.11, 5.11, 5.11, 3, 3, 3, 5.11, 5.11, 5.11, 5.11, 5.11
WBSOLABS = 0.7, 0.7, 0.7, 0.7,  -999,0.7, 0.7,  -999, -999,0.7, 0.7, 0, 0,  -
999, -999,0.7, 0.7, 0.7, 0, 0, 0.7, 0.7, 0.7, 0.7, 0.7, 0.7
/

&WINDOWS
WINZONE = 'main',  'main',  'main',  'main',  'main',  'main',  'main',
'garage'
WEXTSURF = 'north-wall',  'north-wall',  'east-wall',  'south-wall',  'south-
wall',  'south-wall',  'south-clr',  'south'
GLAZTYPE = 'lowe',  'lowe',  'lowe',  'lowe',  'lowe',  'lowe',  'lowe',
'lowe'
WINHGT = 3.0, 1.5, 3.0, 4.5, 7.5, 2.5, 2.0, 3.0
WINLONG = 13.5, 5.0, 4.5, 17.5, 6.2, 3.5, 49.5, 10
WINX = 43.83, 34.83, 20.5, 39.83, 31.13, 18.83, 10.83, 2.0
WINY = 4, 5.5, 2.0, 2.5, 0, 4.19, 1, 2.0
FRAMEPCNT = 0, 0, 0, 0, 0, 0, 0, 0
/

&TROMBEWALLS
/

&SURFACES
NAMESURF = 'north-wall',  'east-wall',  'south-wall',  'west-wall',  'roof-
south',  'roof-north',  'south-clr',  'north',  'east',  'south',  'west'
SURFAZIM = 0, 90, 180, 270, 180, 0, 180, 0, 90, 180, 270
SURFTILT = 90, 90, 90, 90, 21, 21, 90, 90, 90, 90, 90
/

&HVACTYPES
HVACZONE = 'main'
HSETSCD = 'heat1'
VSETSCD = 'vent1'
CSETSCD = 'cool1'
VENTRATE = 10
COILTEMP = 55
/

&FANS
/

&ROCKBINS
/
```

```
&NATURALVENT
/

&TROMBETYPES
/

&WALLTYPES
NAMEWALLTYPE = 'concrete4',  'concrete6',  'sog',  'sog-ins',  'roof',
'roof-att',  'int-wall',  'intb-wall',  'door',  'frame',  'extframe',
'ceiling'
WALLAYER(1,1)  =  'concrete', 'polyiso'
WALLAYER(1,2)  =  'concrete6', 'polyiso'
WALLAYER(1,3)  =  'concrete', 'dirt', 'dirt', 'dirt'
WALLAYER(1,4)  =  'concrete', 'styro-2', 'dirt'
WALLAYER(1,5)  =  'drywall', 'R-38', 'plywood', 'shingle'
WALLAYER(1,6)  =  'drywall', 'plywood', 'shingle'
WALLAYER(1,7)  =  'concrete'
WALLAYER(1,8)  =  'drywall', 'R-1', 'drywall'
WALLAYER(1,9)  =  'R-4'
WALLAYER(1,10) =  'pine'
WALLAYER(1,11) =  'R-19'
WALLAYER(1,12) =  'drywall', 'R-38'
/

&MASSTYPES
NAMEMASSTYPE = 'pine',  'plywood',  'drywall',  'styro-2',  'polyiso',
'concrete',  'concrete6',  'dirt',  'shingle'
MASSCOND = 0.069, 0.069, .098, 0.02, 0.0142, 0.6, 0.6, 0.59, 0.1892
MASSDENS = 27, 27, 50, 1.8, 2.0, 150, 150, 95, 70
MASSCP = 0.29, 0.29, 0.26, 0.29, 0.22, 0.16, 0.16, 0.20, 0.36
MASSTHICK = 0.292, 0.0417, 0.0417, 0.1667, 0.1667, 0.3333, 0.5, 1.5, 0.0313
MASSNODES = 1, 1, 1, 1, 1, 4, 4, 8, 1
/

&PCMTYPES
/

&GLAZINGTYPES
NAMEGLZTYPE = 'lowe2',  'lowe'
GLZFILE = ,  'C:\Program Files\SUNREL\library\windows\hardcoat.win'
UGLAZ = 0.35, 0.35
SHADFACT = .94
GEXTINCT = 0.5
REFINDEX = 1.526
GLZTHICK = 0.09375
NGLAY = 2
/

&ROCKBINTYPES
/

&FANTYPES
/

&OVERHANGTYPES
OHSURFACE = 'south-clr',  'south-wall',  'north-wall'
```

```
OHPROJ = 0.50, 2.00, 2.00
/

&SIDEFINTYPES
/

&SKYLINETYPES
/

&SCHEDULES
NAMESCHEDULE = 'lowe-sc',  'lowe-u',  'heat1',  'heat1',  'vent1',  'vent1',
'cool1',  'cool1',  'I-GAIN-M',  'L-GAIN-M'
SCHDSEASON = 'YEAR',  'YEAR',  'winter',  'summer',  'winter',  'summer',
'winter',  'summer',  'YEAR',  'YEAR'
SCHDL(1,1) = 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664,
0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664,
0.664, 0.664, 0.664, 0.664
SCHDL(1,2) = 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288,
0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288,
0.288, 0.288, 0.288, 0.288
SCHDL(1,3) = 65, 65, 65, 65, 65, 70, 70, 70, 70, 70, 70, 70, 70, 70, 70, 70,
70, 70, 70, 70, 70, 65, 65, 65
SCHDL(1,4) = 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60,
60, 60, 60, 60, 60, 60, 60, 60
SCHDL(1,5) = 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79,
79, 79, 79, 79, 79, 79, 79, 79
SCHDL(1,6) = 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68,
68, 68, 68, 68, 68, 68, 68, 68
SCHDL(1,7) = 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83,
83, 83, 83, 83, 83, 83, 83, 83
SCHDL(1,8) = 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78,
78, 78, 78, 78, 78, 78, 78, 78
SCHDL(1,9) = 0.872, 0.872, 0.872, 0.872, 0.872, 3.668, 3.668, 0.389, 0.389,
0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 3.668, 3.668, 3.668,
3.668, 0.872, 0.872, 0.872
SCHDL(1,10) = 0.399, 0.399, 0.399, 0.399, 0.399, 0.571, 0.571, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.571, 0.571, 0.571, 0.571, 0.399, 0.399,
0.399
/

&OUTPUT
OUTTYPE = 'zones',  'walls',  'zones'
PERIOD = 'M',  'M',  'M'
OUTUNITS = 'E',  'E',  'E'
OUTSEASON = 'winter',  'winter',  'YEAR'
FRMT = 'Y',  'Y',  'Y'
IOCOMP = 1,  -999,1
IOPAGE = -999, -999, -999
/

&SEASONS
NAMESEASON = 'YEAR',  'winter',  'summer',  'Jan',  'Feb',  'Mar',  'Apr',
'May',  'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
SEASTRTMN = 'JAN',  'OCT',  'MAY',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
SEASTOPMN = 'DEC',  'APR',  'SEP',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
```

```
DAYOFWEEK = 'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',
'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL'
SEASTRTDY = 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01
SEASTOPDY = 31, 30, 30, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31
/

&STATIONS
NAMESTATION = 'pueblo'
WEATHERFILE = 'C:\Program Files\SUNREL\library\weatherfiles\pueblo.tmy'
WEATYPE = 'TMY'
WSTRTMN = 'Jan'
WSTOPMN = 'Dec'
SITELAT = 38.18
SITELONG = 104.3
ELEV = 4641
TERRAIN = 2
SHIELD = 1
WSTRTDY = 1
WSTOPDY = 31
/

&PARAMETERS
/
```

This is an 1,870 ft^2 house built by Tierra Concrete Homes in 1996 at 1134
West McCulloch, in Pueblo CO.

The building description is updated to account for changes between
construction plans and measured values post construction. The change
reflects a 9% decrease in measured glazing area from plans.

Created by: Michael Smith
Created on: 7/1/98 11:13:23 AM
Last modified by: Michael Smith
Last modified on: 2/28/00 11:00:21 AM

```
&RUNS
LABEL = 'Run1'
STATION = 'pueblo'
RSTRTMN = 'JAN'
RSTOPMN = 'DEC'
RUNITS = 'E'
DDTYPE = 'US'
GREFL = 0.3
GTEMP = 55
RSTRTDY = 01
RSTOPDY = 31
/

&ZONES
ZONENAME = 'main',  'garage',  'attic'
SENSSCD = 'I-GAIN-M'
LATSCD = 'L-GAIN-M'
ZAREA = 1870, 473, 748
ZHGT = 9.333, 8, 2
ZONEZ = , , 8
ZACH = 0.20, 4.00, 4.00
SOL2AIR = 0.2, 0.2, 0.0
SOLLOST = 0.05, 0.05, 0.00
GAINSENS = , 0.000, 0.0
GAINLAT = , 0.000, 0.0
/

&INTERZONES
/

&WALLS
WALLTYPE = 'concrete4', 'concrete6', 'concrete4', 'concrete6',
'concrete6', 'concrete6', 'extframe', 'ceiling', 'extframe', 'roof-att',
'roof', 'sog', 'sog-ins', 'int-wall', 'intb-wall', 'concrete4',
'concrete4', 'concrete4', 'sog', 'sog-ins', 'roof-att', 'frame',
'frame', 'frame', 'frame', 'frame'
WFRNTZONE = 'main', 'main', 'main', 'main', 'main', 'garage', 'main',
'main', 'main', 'attic', 'main', 'main', 'main', 'main', 'main',
'garage', 'garage', 'garage', 'garage', 'garage', 'garage', 'garage',
'main', 'main', 'main', 'main'
WBACKZONE = 'north-wall', 'east-wall', 'south-wall', 'west-wall',
'garage', 'east', 'south-clr', 'attic', 'attic', 'roof-south', 'roof-
north', 'GROUND', 'AMBIENT', 'main', 'main', 'south', 'west', 'north',
```

```
'GROUND',  'AMBIENT',  'AMBIENT',  'north',  'north-wall',  'east-wall',
'south-wall',  'south-clr'
WALLHGT = 8.0, 8.0, 8.0, 8.0, 8.0, 8.0, 4.0, 12.0, 4.0, 15.0, 18.0, 19.0,
11.0, 8.0, 8.0, 8.0, 8.0, 8.0, 18, 8, 22, 8.0, 8.0, 8.0, 8.0, 4.0
WALLONG = 62.33, 30.0, 62.33, 12, 18, 4, 62.33, 62.33, 62.33, 62.33, 62.33,
62.33, 62.33, 160, 20.0, 21.5, 22.0, 21.5, 17.5, 19.75, 22, 21.5, 62.33, 30,
62.33, 62.33
WALLPERCENT = 93, 98, 94, , , , 88, , , , , , , , , , , 43, , , , 57, 7, 2,
6, 12
WFRNTH = 1.46, 1.46, 1.46, 1.46, 1.46, 1.46, 1.46, 1.3, 1.46, 1.3, 1.3, 1.2,
1.2, 1.46, 1.46, 1.46, 1.46, 1.46, 1.2, 1.2, 1.3, 1.46, 1.46, 1.46, 1.46,
1.46
WFSOLABS = -999, -999, -999, -999, -999, -999, -999, -999, -999, -999, -
999,.32, .18,  -999, -999, -999, -999, -999, -999, -999, -999, -999, -999, -
999, -999, -999
WBACKH = 5.11, 5.11, 5.11, 5.11, 1.46, 5.11, 5.11, 1.2, 1.46, 3, 3, 3, 3,
1.46, 1.46, 5.11, 5.11, 5.11, 3, 3, 3, 5.11, 5.11, 5.11, 5.11, 5.11
WBSOLABS = 0.7, 0.7, 0.7, 0.7,  -999,0.7, 0.7,  -999, -999,0.7, 0.7, 0, 0,  -
999, -999,0.7, 0.7, 0.7, 0, 0, 0.7, 0.7, 0.7, 0.7, 0.7, 0.7
/

&WINDOWS
WINZONE = 'main',  'main',  'main',  'main',  'main',  'main',  'main',
'garage'
WEXTSURF = 'north-wall',  'north-wall',  'east-wall',  'south-wall',  'south-
wall',  'south-wall',  'south-clr',  'south'
GLAZTYPE = 'lowe',  'lowe',  'lowe',  'lowe',  'lowe',  'lowe',  'lowe',
'lowe'
WINHGT = 3.35, 1.8125, 3.35, 4.77, 6.73, 2.81, 2.5, 3.0
WINLONG = 14.56, 5.7, 4.85, 19.27, 7.77, 3.85, 49.5, 10
WINX = 43.83, 34.83, 20.5, 39.83, 31.13, 18.83, 10.83, 2.0
WINY = 3.65, 5.2, 3.65, 2.2, 0, 4.19, 1, 2.0
FRAMEPCNT = 25, 40, 25, 22, 15, 28, 25, 25
/

&TROMBEWALLS
/

&SURFACES
NAMESURF = 'north-wall',  'east-wall',  'south-wall',  'west-wall',  'roof-
south',  'roof-north',  'south-clr',  'north',  'east',  'south',  'west'
SURFAZIM = 0, 90, 180, 270, 180, 0, 180, 0, 90, 180, 270
SURFTILT = 90, 90, 90, 90, 21, 21, 90, 90, 90, 90, 90
/

&HVACTYPES
HVACZONE = 'main'
HSETSCD = 'heat1'
VSETSCD = 'vent1'
CSETSCD = 'cool1'
VENTRATE = 10
COILTEMP = 55
/

&FANS
/
```

```
&ROCKBINS
/

&NATURALVENT
/

&TROMBETYPES
/

&WALLTYPES
NAMEWALLTYPE = 'concrete4',  'concrete6',  'sog',  'sog-ins',  'roof',
'roof-att',  'int-wall',  'intb-wall',  'door',  'frame',  'extframe',
'ceiling'
WALLAYER(1,1) =  'concrete', 'polyiso'
WALLAYER(1,2) =  'concrete6', 'polyiso'
WALLAYER(1,3) =  'concrete', 'dirt', 'dirt', 'dirt'
WALLAYER(1,4) =  'concrete', 'styro-2', 'dirt'
WALLAYER(1,5) =  'drywall', 'R-38', 'plywood', 'shingle'
WALLAYER(1,6) =  'drywall', 'plywood', 'shingle'
WALLAYER(1,7) =  'concrete'
WALLAYER(1,8) =  'drywall', 'R-1', 'drywall'
WALLAYER(1,9) =  'R-4'
WALLAYER(1,10) =  'pine'
WALLAYER(1,11) =  'R-19'
WALLAYER(1,12) =  'drywall', 'R-38'
/

&MASSTYPES
NAMEMASSTYPE = 'pine',  'plywood',  'drywall',  'styro-2',  'polyiso',
'concrete',  'concrete6',  'dirt',  'shingle'
MASSCOND = 0.069, 0.069, 0.098, 0.02, 0.0142, 0.6, 0.6, 0.59, 0.1892
MASSDENS = 27, 27, 50, 1.8, 2.0, 150, 150, 95, 70
MASSCP = 0.29, 0.29, 0.26, 0.29, 0.22, 0.16, 0.16, 0.2, 0.36
MASSTHICK = 0.292, 0.0417, 0.0417, 0.1667, 0.1667, 0.3333, 0.5, 1.5, 0.0313
MASSNODES = 1, 1, 1, 1, 1, 4, 4, 8, 1
/

&PCMTYPES
/

&GLAZINGTYPES
NAMEGLZTYPE = 'lowe3',  'lowe'
GLZFILE = ,  'C:\Program Files\SUNREL\library\windows\hardcoat.win'
UGLAZ = 0.35, 0.35
SHADFACT = 0.94
GEXTINCT = .5
REFINDEX = 1.526
GLZTHICK = 0.125
NGLAY = 2
/

&ROCKBINTYPES
/

&FANTYPES
/
```

```
&OVERHANGTYPES
OHSURFACE = 'south-clr',  'south-wall',  'north-wall'
OHPROJ = 0.50, 2.00, 2.00
/

&SIDEFINTYPES
/

&SKYLINETYPES
/

&SCHEDULES
NAMESCHEDULE = 'lowe-sc',  'lowe-u',  'heat1',  'heat1',  'vent1',  'vent1',
'cool1',  'cool1',  'I-GAIN-M',  'L-GAIN-M'
SCHDSEASON = 'YEAR',  'YEAR',  'winter',  'summer',  'winter',  'summer',
'winter',  'summer',  'YEAR',  'YEAR'
SCHDL(1,1) = 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664,
0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664, 0.664,
0.664, 0.664, 0.664, 0.664
SCHDL(1,2) = 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288,
0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288, 0.288,
0.288, 0.288, 0.288, 0.288
SCHDL(1,3) = 65, 65, 65, 65, 65, 70, 70, 70, 70, 70, 70, 70, 70, 70, 70, 70,
70, 70, 70, 70, 70, 65, 65, 65
SCHDL(1,4) = 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60,
60, 60, 60, 60, 60, 60, 60, 60
SCHDL(1,5) = 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79,
79, 79, 79, 79, 79, 79, 79, 79
SCHDL(1,6) = 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68,
68, 68, 68, 68, 68, 68, 68, 68
SCHDL(1,7) = 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83,
83, 83, 83, 83, 83, 83, 83, 83
SCHDL(1,8) = 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78,
78, 78, 78, 78, 78, 78, 78, 78
SCHDL(1,9) = 0.872, 0.872, 0.872, 0.872, 0.872, 3.668, 3.668, 0.389, 0.389,
0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 3.668, 3.668, 3.668,
3.668, 0.872, 0.872, 0.872
SCHDL(1,10) = 0.399, 0.399, 0.399, 0.399, 0.399, 0.571, 0.571, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.571, 0.571, 0.571, 0.571, 0.399, 0.399,
0.399
/

&OUTPUT
OUTTYPE = 'ambient',  'zones',  'walls',  'zones'
PERIOD = 'M',  'M',  'M',  'M'
OUTUNITS = 'E',  'E',  'E',  'E'
OUTSEASON = 'YEAR',  'winter',  'winter',  'YEAR'
FRMT = 'Y',  'Y',  'Y',  'Y'
IOCOMP = -999,1,  -999,1
IOPAGE = -999, -999, -999, -999
/

&SEASONS
NAMESEASON = 'YEAR',  'winter',  'summer',  'Jan',  'Feb',  'Mar',  'Apr',
'May',  'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
SEASTRTMN = 'JAN',  'OCT',  'MAY',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
```

```
SEASTOPMN = 'DEC',  'APR',  'SEP',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
DAYOFWEEK = 'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',
'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL'
SEASTRTDY = 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01
SEASTOPDY = 31, 30, 30, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31
/

&STATIONS
NAMESTATION = 'pueblo'
WEATHERFILE = 'C:\Program Files\SUNREL\library\weatherfiles\pueblo.tmy'
WEATYPE = 'TMY'
WSTRTMN = 'Jan'
WSTOPMN = 'Dec'
SITELAT = 38.18
SITELONG = 104.3
ELEV = 4641
TERRAIN = 2
SHIELD = 1
WSTRTDY = 1
WSTOPDY = 31
/

&PARAMETERS
/
```

<u>Calibrated Model</u>
This is an 1,870 ft^2 house built by Tierra Concrete Homes in 1996 at 1134
West McCulloch, in Pueblo CO.

The calibrated version of As-built with changes made to more closely match
the performance of the actual building.

Created by: Michael Smith
Created on: 7/1/98 11:13:23 AM
Last modified by: Michael Smith
Last modified on: 2/25/00 10:34:19 AM

```
&RUNS
LABEL = 'Run1'
STATION = 'pueblo'
RSTRTMN = 'JAN'
RSTOPMN = 'DEC'
RUNITS = 'E'
DDTYPE = 'US'
GREFL = 0.3
GTEMP = 55
RSTRTDY = 01
RSTOPDY = 31
/

&ZONES
ZONENAME = 'main',  'garage',  'attic'
SENSSCD = 'I-GAIN-M'
LATSCD = 'L-GAIN-M'
ZAREA = 1870, 473, 748
ZHGT = 9.333, 8, 2
ZONEZ = , , 8
ZACH = , 4.00, 4.00
ZLEAK = 62
SOL2AIR = 0.2, 0.2, 0.0
SOLLOST = 0.05, 0.05, 0.00
GAINSENS = , 0.000, 0.0
GAINLAT = , 0.000, 0.0
/

&INTERZONES
/

&WALLS
WALLTYPE = 'concrete4', 'concrete6', 'concrete4', 'concrete6',
'concrete6', 'concrete6', 'extframe', 'ceiling', 'extframe', 'roof-att',
'roof', 'sog', 'sog-ins', 'int-wall', 'intb-wall', 'concrete4',
'concrete4', 'concrete4', 'sog', 'sog-ins', 'roof-att', 'frame',
'frame', 'frame', 'frame', 'frame'
WFRNTZONE = 'main', 'main', 'main', 'main', 'main', 'garage', 'main',
'main', 'main', 'attic', 'main', 'main', 'main', 'main', 'main',
'garage', 'garage', 'garage', 'garage', 'garage', 'garage', 'garage',
'main', 'main', 'main', 'main'
WBACKZONE = 'north-wall', 'east-wall', 'south-wall', 'west-wall',
'garage', 'east', 'south-clr', 'attic', 'attic', 'roof-south', 'roof-
north', 'GROUND', 'AMBIENT', 'main', 'main', 'south', 'west', 'north',
```

```
'GROUND', 'AMBIENT', 'AMBIENT', 'north', 'north-wall', 'east-wall',
'south-wall', 'south-clr'
WALLHGT = 8.0, 8.0, 8.0, 8.0, 8.0, 8.0, 4.0, 12.0, 4.0, 15.0, 18.0, 19.0,
11.0, 8.0, 8.0, 8.0, 8.0, 8.0, 18, 8, 22, 8.0, 8.0, 8.0, 8.0, 4.0
WALLONG = 62.33, 30.0, 62.33, 12, 18, 4, 62.33, 62.33, 62.33, 62.33, 62.33,
62.33, 62.33, 160, 20.0, 21.5, 22.0, 21.5, 17.5, 19.75, 22, 21.5, 62.33, 30,
62.33, 62.33
WALLPERCENT = 93, 98, 94, , , , 88, , , , , , , , , , , 43, , , , 57, 7, 2,
6, 12
WFRNTH = 1.46, 1.46, 1.46, 1.46, 1.46, 1.46, 1.46, 1.3, 1.46, 1.3, 1.3, 1.2,
1.2, 1.46, 1.46, 1.46, 1.46, 1.46, 1.2, 1.2, 1.3, 1.46, 1.46, 1.46, 1.46,
1.46
WFSOLABS = -999, -999, -999, -999, -999, -999, -999, -999, -999, -999, -
999,.32, .18,  -999, -999, -999, -999, -999, -999, -999, -999, -999, -999, -
999, -999, -999
WBACKH = 5.11, 5.11, 5.11, 5.11, 1.46, 5.11, 5.11, 1.2, 1.46, 3, 3, 3, 3,
1.46, 1.46, 5.11, 5.11, 5.11, 3, 3, 3, 5.11, 5.11, 5.11, 5.11, 5.11
WBSOLABS = 0.7, 0.7, 0.7, 0.7,  -999,0.7, 0.7,  -999, -999,0.7, 0.7, 0, 0,  -
999, -999,0.7, 0.7, 0.7, 0, 0, 0.7, 0.7, 0.7, 0.7, 0.7, 0.7
/

&WINDOWS
WINZONE = 'main', 'main', 'main', 'main', 'main', 'main', 'main',
'garage'
WEXTSURF = 'north-wall', 'north-wall', 'east-wall', 'south-wall', 'south-
wall', 'south-wall', 'south-clr', 'south'
GLAZTYPE = 'lowe', 'lowe', 'lowe', 'lowe', 'lowe', 'lowe', 'lowe',
'lowe'
WINHGT = 3.35, 1.8125, 3.35, 4.77, 6.73, 2.81, 2.5, 3.0
WINLONG = 14.56, 5.7, 4.85, 19.27, 7.77, 3.85, 49.5, 10
WINX = 43.83, 34.83, 20.5, 39.83, 31.13, 18.83, 10.83, 2.0
WINY = 3.65, 5.2, 3.65, 2.2, 0, 4.19, 1, 2.0
FRAMEPCNT = 25, 40, 25, 22, 15, 28, 25, 25
/

&TROMBEWALLS
/

&SURFACES
NAMESURF = 'north-wall', 'east-wall', 'south-wall', 'west-wall', 'roof-
south', 'roof-north', 'south-clr', 'north', 'east', 'south', 'west'
SURFAZIM = 0, 90, 180, 270, 180, 0, 180, 0, 90, 180, 270
SURFTILT = 90, 90, 90, 90, 21, 21, 90, 90, 90, 90, 90
/

&HVACTYPES
HVACZONE = 'main'
HSETSCD = 'heat1'
VSETSCD = 'vent1'
CSETSCD = 'cool1'
VENTRATE = 10
COILTEMP = 55
/

&FANS
/
```

```
&ROCKBINS
/

&NATURALVENT
/

&TROMBETYPES
/

&WALLTYPES
NAMEWALLTYPE = 'concrete4',  'concrete6',  'sog',  'sog-ins',  'roof',
'roof-att',  'int-wall',  'intb-wall',  'door',  'frame',  'extframe',
'ceiling'
WALLAYER(1,1) =  'concrete', 'polyiso'
WALLAYER(1,2) =  'concrete6', 'polyiso'
WALLAYER(1,3) =  'concrete', 'dirt', 'dirt', 'dirt'
WALLAYER(1,4) =  'concrete', 'styro-2', 'dirt'
WALLAYER(1,5) =  'drywall', 'R-38', 'plywood', 'shingle'
WALLAYER(1,6) =  'drywall', 'plywood', 'shingle'
WALLAYER(1,7) =  'concrete'
WALLAYER(1,8) =  'drywall', 'R-1', 'drywall'
WALLAYER(1,9) =  'R-4'
WALLAYER(1,10) =  'pine'
WALLAYER(1,11) =  'R-19'
WALLAYER(1,12) =  'drywall', 'R-38'
/

&MASSTYPES
NAMEMASSTYPE = 'pine',  'plywood',  'drywall',  'styro-2',  'polyiso',
'concrete',  'concrete6',  'dirt',  'shingle'
MASSCOND = 0.069, 0.069, 0.098, 0.02, 0.0142, 0.6, 0.6, 0.59, 0.1892
MASSDENS = 27, 27, 50, 1.8, 2.0, 150, 150, 95, 70
MASSCP = 0.29, 0.29, 0.26, 0.29, 0.22, 0.16, 0.16, 0.2, 0.36
MASSTHICK = 0.292, 0.0417, 0.0417, 0.1667, 0.1667, 0.3333, 0.5, 1.5, 0.0313
MASSNODES = 1, 1, 1, 1, 1, 4, 4, 8, 1
/

&PCMTYPES
/

&GLAZINGTYPES
NAMEGLZTYPE = 'lowe'
GLZFILE = 'C:\Program Files\SUNREL\library\windows\hardcoat.win'
UGLAZ = 0.35
SHADFACT = 0.7
/

&ROCKBINTYPES
/

&FANTYPES
/

&OVERHANGTYPES
OHSURFACE = 'south-clr',  'south-wall',  'north-wall'
OHPROJ = 0.50, 2.00, 2.00
/
```

```
&SIDEFINTYPES
/

&SKYLINETYPES
/

&SCHEDULES
NAMESCHEDULE = 'heat1',  'heat1',  'vent1',  'vent1',  'cool1',  'cool1',
'I-GAIN-M',  'L-GAIN-M'
SCHDSEASON = 'winter',  'summer',  'winter',  'summer',  'winter',  'summer',
'YEAR',  'YEAR'
SCHDL(1,1) = 65, 65, 65, 65, 65, 70, 70, 70, 70, 70, 70, 70, 70, 70, 70, 70,
70, 70, 70, 70, 70, 65, 65, 65
SCHDL(1,2) = 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60,
60, 60, 60, 60, 60, 60, 60, 60
SCHDL(1,3) = 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79,
79, 79, 79, 79, 79, 79, 79, 79
SCHDL(1,4) = 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68,
68, 68, 68, 68, 68, 68, 68, 68
SCHDL(1,5) = 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83,
83, 83, 83, 83, 83, 83, 83, 83
SCHDL(1,6) = 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78,
78, 78, 78, 78, 78, 78, 78, 78
SCHDL(1,7) = 0.872, 0.872, 0.872, 0.872, 0.872, 3.668, 3.668, 0.389, 0.389,
0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 3.668, 3.668, 3.668,
3.668, 0.872, 0.872, 0.872
SCHDL(1,8) = 0.399, 0.399, 0.399, 0.399, 0.399, 0.571, 0.571, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.571, 0.571, 0.571, 0.571, 0.399, 0.399,
0.399
/

&OUTPUT
OUTTYPE = 'zones',  'walls',  'zones',  'zones'
PERIOD = 'M',  'M',  'M',  'H'
OUTUNITS = 'E',  'E',  'E',  'E'
OUTSEASON = 'winter',  'winter',  'YEAR',  'YEAR'
FRMT = 'Y',  'Y',  'Y',  'N'
IOCOMP = 1,  -999,1, 1
IOPAGE = -999, -999, -999,7
/

&SEASONS
NAMESEASON = 'YEAR',  'winter',  'summer',  'Jan',  'Feb',  'Mar',  'Apr',
'May',  'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
SEASTRTMN = 'JAN',  'OCT',  'MAY',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
SEASTOPMN = 'DEC',  'APR',  'SEP',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
DAYOFWEEK = 'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',
'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL'
SEASTRTDY = 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01
SEASTOPDY = 31, 30, 30, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31
/

&STATIONS
NAMESTATION = 'pueblo'
```

```
WEATHERFILE = 'C:\Program Files\SUNREL\library\weatherfiles\pueblo.tmy'
WEATYPE = 'TMY'
WSTRTMN = 'Jan'
WSTOPMN = 'Dec'
SITELAT = 38.18
SITELONG = 104.3
ELEV = 4641
TERRAIN = 2
SHIELD = 1
WSTRTDY = 1
WSTOPDY = 31
/

&PARAMETERS
/
```

<u>Improved Model</u>
This is an 1,870 ft^2 house built by Tierra Concrete Homes in 1996 at 1134
West McCulloch, in Pueblo CO.

The calibrated version of As-built with changes made to more closely match
the performance of the actual building.

Created by: Michael Smith
Created on: 7/1/98 11:13:23 AM
Last modified by: Michael Smith
Last modified on: 3/2/00 9:12:38 AM

```
&RUNS
LABEL = 'Run1'
STATION = 'pueblo'
RSTRTMN = 'JAN'
RSTOPMN = 'DEC'
RUNITS = 'E'
DDTYPE = 'US'
GREFL = 0.3
GTEMP = 55
RSTRTDY = 01
RSTOPDY = 31
/

&ZONES
ZONENAME = 'main',  'garage',  'attic'
SENSSCD = 'I-GAIN-M'
LATSCD = 'L-GAIN-M'
ZAREA = 1870, 473, 748
ZHGT = 9.333, 8, 2
ZONEZ = , , 8
ZACH = , 4.00, 4.00
ZLEAK = 62
SOL2AIR = 0.2, 0.2, 0.0
SOLLOST = 0.05, 0.05, 0.00
GAINSENS = , 0.000, 0.0
GAINLAT = , 0.000, 0.0
/

&INTERZONES
/

&WALLS
WALLTYPE = 'concrete4', 'concrete6', 'concrete4', 'concrete6',
'concrete6', 'concrete6', 'extframe', 'ceiling', 'extframe', 'roof-att',
'roof', 'sog', 'sog-ins', 'int-wall', 'intb-wall', 'concrete4',
'concrete4', 'concrete4', 'sog', 'sog-ins', 'roof-att', 'frame',
'frame', 'frame', 'frame', 'frame'
WFRNTZONE = 'main', 'main', 'main', 'main', 'main', 'garage', 'main',
'main', 'main', 'attic', 'main', 'main', 'main', 'main', 'main',
'garage', 'garage', 'garage', 'garage', 'garage', 'garage', 'garage',
'main', 'main', 'main', 'main'
WBACKZONE = 'north-wall', 'east-wall', 'south-wall', 'west-wall',
'garage', 'east', 'south-clr', 'attic', 'attic', 'roof-south', 'roof-
north', 'GROUND', 'AMBIENT', 'main', 'main', 'south', 'west', 'north',
```

```
'GROUND',  'AMBIENT',  'AMBIENT',  'north',  'north-wall',  'east-wall',
'south-wall',  'south-clr'
WALLHGT = 8.0, 8.0, 8.0, 8.0, 8.0, 8.0, 4.0, 12.0, 4.0, 15.0, 18.0, 19.0,
11.0, 8.0, 8.0, 8.0, 8.0, 8.0, 18, 8, 22, 8.0, 8.0, 8.0, 8.0, 4.0
WALLONG = 62.33, 30.0, 62.33, 12, 18, 4, 62.33, 62.33, 62.33, 62.33, 62.33,
62.33, 62.33, 160, 20.0, 21.5, 22.0, 21.5, 17.5, 19.75, 22, 21.5, 62.33, 30,
62.33, 62.33
WALLPERCENT = 93, 98, 94, , , , 88, , , , , , , , , , , , 43, , , , 57, 7, 2,
6, 12
WFRNTH = 1.46, 1.46, 1.46, 1.46, 1.46, 1.46, 1.46, 1.3, 1.46, 1.3, 1.3, 1.2,
1.2, 1.46, 1.46, 1.46, 1.46, 1.46, 1.2, 1.2, 1.3, 1.46, 1.46, 1.46, 1.46,
1.46
WFSOLABS = -999, -999, -999, -999, -999, -999, -999, -999, -999, -999, -
999,.32, .18,  -999, -999, -999, -999, -999, -999, -999, -999, -999, -999, -
999, -999, -999
WBACKH = 5.11, 5.11, 5.11, 5.11, 1.46, 5.11, 5.11, 1.2, 1.46, 3, 3, 3, 3,
1.46, 1.46, 5.11, 5.11, 5.11, 3, 3, 3, 5.11, 5.11, 5.11, 5.11, 5.11
WBSOLABS = 0.7, 0.7, 0.7, 0.7,  -999,0.7, 0.7,  -999, -999,0.7, 0.7, 0, 0,  -
999, -999,0.7, 0.7, 0.7, 0, 0, 0.7, 0.7, 0.7, 0.7, 0.7, 0.7
/

&WINDOWS
WINZONE = 'main',  'main',  'main',  'main',  'main',  'main',  'main',
'garage'
WEXTSURF = 'north-wall',  'north-wall',  'east-wall',  'south-wall',  'south-
wall',  'south-wall',  'south-clr',  'south'
GLAZTYPE = 'lowe2',  'lowe2',  'lowe2',  'lowe',  'lowe',  'lowe',  'lowe',
'lowe'
WINHGT = 3.35, 1.8125, 3.35, 4.77, 6.73, 2.81, 2.5, 3.0
WINLONG = 14.56, 5.7, 4.85, 19.27, 7.77, 3.85, 49.5, 10
WINX = 43.83, 34.83, 20.5, 39.83, 31.13, 18.83, 10.83, 2.0
WINY = 3.65, 5.2, 3.65, 2.2, 0, 4.19, 1, 2.0
FRAMEPCNT = 25, 40, 25, 22, 15, 28, 25, 25
/

&TROMBEWALLS
/

&SURFACES
NAMESURF = 'north-wall',  'east-wall',  'south-wall',  'west-wall',  'roof-
south',  'roof-north',  'south-clr',  'north',  'east',  'south',  'west'
SURFAZIM = 0, 90, 180, 270, 180, 0, 180, 0, 90, 180, 270
SURFTILT = 90, 90, 90, 90, 21, 21, 90, 90, 90, 90, 90
/

&HVACTYPES
HVACZONE = 'main'
HSETSCD = 'heat1'
VSETSCD = 'vent1'
CSETSCD = 'cool1'
VENTRATE = 10
COILTEMP = 55
/

&FANS
/
```

```
&ROCKBINS
/

&NATURALVENT
/

&TROMBETYPES
/

&WALLTYPES
NAMEWALLTYPE = 'concrete4',  'concrete6',  'sog',  'sog-ins',  'roof',
'roof-att',  'int-wall',  'intb-wall',  'door',  'frame',  'extframe',
'ceiling'
WALLAYER(1,1) =  'concrete', 'polyiso'
WALLAYER(1,2) =  'concrete6', 'polyiso'
WALLAYER(1,3) =  'concrete', 'styro-2', 'dirt', 'dirt', 'dirt'
WALLAYER(1,4) =  'concrete', 'styro-2', 'dirt'
WALLAYER(1,5) =  'drywall', 'R-38', 'plywood', 'shingle'
WALLAYER(1,6) =  'drywall', 'plywood', 'shingle'
WALLAYER(1,7) =  'concrete'
WALLAYER(1,8) =  'drywall', 'R-1', 'drywall'
WALLAYER(1,9) =  'R-4'
WALLAYER(1,10) =  'pine'
WALLAYER(1,11) =  'R-19'
WALLAYER(1,12) =  'drywall', 'R-38'
/

&MASSTYPES
NAMEMASSTYPE = 'pine',  'plywood',  'drywall',  'styro-2',  'polyiso',
'concrete',  'concrete6',  'dirt',  'shingle'
MASSCOND = 0.069, 0.069, 0.098, 0.02, 0.0142, 0.6, 0.6, 0.59, 0.1892
MASSDENS = 27, 27, 50, 1.8, 2.0, 150, 150, 95, 70
MASSCP = 0.29, 0.29, 0.26, 0.29, 0.22, 0.16, 0.16, 0.2, 0.36
MASSTHICK = 0.292, 0.0417, 0.0417, 0.1666, 0.25, 0.3333, 0.5, 1.5, 0.0313
MASSNODES = 1, 1, 1, 1, 1, 4, 4, 8, 1
/

&PCMTYPES
/

&GLAZINGTYPES
NAMEGLZTYPE = 'lowe',  'lowe2'
GLZFILE = 'C:\Program Files\SUNREL\library\windows\hardcoat.win',
'C:\Program Files\SUNREL\library\windows\Doublowe.win'
UGLAZ = 0.35, 0.28
SHADFACT = 0.75, 0.7
/

&ROCKBINTYPES
/

&FANTYPES
/

&OVERHANGTYPES
OHSURFACE = 'south-clr',  'south-wall',  'north-wall'
OHPROJ = 0.50, 2.00, 2.00
```

```
/

&SIDEFINTYPES
/

&SKYLINETYPES
/

&SCHEDULES
NAMESCHEDULE = 'heat1',  'heat1', 'vent1',  'vent1', 'cool1', 'cool1',
'I-GAIN-M',  'L-GAIN-M'
SCHDSEASON = 'winter',  'summer',  'winter',  'summer', 'winter',  'summer',
'YEAR',  'YEAR'
SCHDL(1,1) = 65, 65, 65, 65, 65, 70, 70, 70, 70, 70, 70, 70, 70, 70, 70, 70,
70, 70, 70, 70, 70, 65, 65, 65
SCHDL(1,2) = 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60, 60,
60, 60, 60, 60, 60, 60, 60, 60
SCHDL(1,3) = 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79, 79,
79, 79, 79, 79, 79, 79, 79, 79
SCHDL(1,4) = 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68, 68,
68, 68, 68, 68, 68, 68, 68, 68
SCHDL(1,5) = 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83, 83,
83, 83, 83, 83, 83, 83, 83, 83
SCHDL(1,6) = 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78, 78,
78, 78, 78, 78, 78, 78, 78, 78
SCHDL(1,7) = 0.872, 0.872, 0.872, 0.872, 0.872, 3.668, 3.668, 0.389, 0.389,
0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 0.389, 3.668, 3.668, 3.668,
3.668, 0.872, 0.872, 0.872
SCHDL(1,8) = 0.399, 0.399, 0.399, 0.399, 0.399, 0.571, 0.571, 0.0, 0.0, 0.0,
0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.571, 0.571, 0.571, 0.571, 0.399, 0.399,
0.399
/

&OUTPUT
OUTTYPE = 'zones',  'walls',  'zones'
PERIOD = 'M',  'M',  'M'
OUTUNITS = 'E',  'E',  'E'
OUTSEASON = 'winter',  'winter',  'YEAR'
FRMT = 'Y',  'Y',  'Y'
IOCOMP = 1,  -999,1
IOPAGE = -999, -999, -999
/

&SEASONS
NAMESEASON = 'YEAR',  'winter',  'summer',  'Jan',  'Feb',  'Mar',  'Apr',
'May',  'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
SEASTRTMN = 'JAN',  'OCT',  'MAY',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
SEASTOPMN = 'DEC',  'APR',  'SEP',  'Jan',  'Feb',  'Mar',  'Apr',  'May',
'Jun',  'Jul',  'Aug',  'Sep',  'Oct',  'Nov',  'Dec'
DAYOFWEEK = 'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',
'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL',  'ALL'
SEASTRTDY = 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01, 01
SEASTOPDY = 31, 30, 30, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31
/

&STATIONS
```

```
NAMESTATION = 'pueblo'
WEATHERFILE = 'C:\Program Files\SUNREL\library\weatherfiles\pueblo.tmy'
WEATYPE = 'TMY'
WSTRTMN = 'Jan'
WSTOPMN = 'Dec'
SITELAT = 38.18
SITELONG = 104.3
ELEV = 4641
TERRAIN = 2
SHIELD = 1
WSTRTDY = 1
WSTOPDY = 31
/

&PARAMETERS
/
```

Appendix G—Data-Logger Program and Sample Data Record

Data-Logger Program
```
;{CR10}
;Tierra Concrete Homes Data Acquisition
;Author:  Vinay Shah
;Last Updated:  7/24/96

*Table 1 Program
  01: 5.0        Execution Interval (seconds)

1:  Set Port(s) (P20)
 1: 9999     C8..C5 = nc/nc/nc/nc
 2: 9933     C4..C1 = nc/nc/1ms/1ms

;Switch Multiplexer On
2:  Do (P86)
 1: 42       Set Port 2 High

;Multiplexer Stuff
3:  Full Bridge (P6)
 1: 1          Reps
 2: 22         ñ 7.5 mV 60 Hz Rejection Range
 3: 1          DIFF Channel
 4: 1          Excite all reps w/Exchan 1
 5: 350        mV Excitation
 6: 12         Loc [ MultRef   ]
 7: -.001      Mult
 8: .09707     Offset

4:  BR Transform Rf[X/(1-X)] (P59)
 1: 1          Reps
 2: 12         Loc [ MultRef   ]
 3: 10.025     Multiplier (Rf)

5:  Temperature RTD (P16)
 1: 1          Reps
 2: 12         R/RO Loc [ MultRef   ]
 3: 12         Loc [ MultRef   ]
 4: 1.0        Mult
 5: 0.0        Offset

;TC Loop
```

```
6:  Beginning of Loop (P87)
 1: 0         Delay
 2: 7         Loop Count


;Clock Multiplexer
7:  Do (P86)
 1: 71        Pulse Port 1


8:  Do (P86)
 1: 71        Pulse Port 1


;Internal Temp (7 TC)
9:  Thermocouple Temp (DIFF) (P14)
 1: 1         Reps
 2: 22        ñ 7.5 mV 60 Hz Rejection Range
 3: 1         DIFF Channel
 4: 1         Type T (Copper-Constantan)
 5: 12        Ref Temp Loc [ MultRef   ]
 6: 1         Loc [ TCcsfam   ]
 7: 1.0       Mult
 8: 0.0       Offset


10:  End (P95)


;Switch off Multiplexer
11:  Do (P86)
 1: 52        Set Port 2 Low


;Solar Radiation
12:  Volt (Diff) (P2)
 1: 1         Reps
 2: 22        ñ 7.5 mV 60 Hz Rejection Range
 3: 2         DIFF Channel
 4: 13        Loc [ SolarRad  ]
 5: 200       Mult
 6: 0.0       Offset


;Outside Relative Humidity
13:  Volts (SE) (P1)
 1: 1         Reps
 2: 25        ñ 2500 mV 60 Hz Rejection Range
 3: 5         SE Channel
 4: 14        Loc [ RHout     ]
 5: 0.1       Mult
 6: 0.0       Offset


;Outside Temperature
14:  Volts (SE) (P1)
 1: 1         Reps
 2: 25        ñ 2500 mV 60 Hz Rejection Range
 3: 6         SE Channel
 4: 15        Loc [ Tout      ]
 5: 0.1       Mult
 6: -40       Offset


;Wind Speed
15:  Pulse (P3)
```

```
 1: 1          Reps
 2: 1          Pulse Input Channel
 3: 21         Low Level AC, Output Hz
 4: 16         Loc [ WSmph     ]
 5: 1.677      Mult
 6: 0.4        Offset

;Wind Dir
16:  Excite-Delay (SE) (P4)
 1: 1          Reps
 2: 5          ñ 2500 mV Slow Range
 3: 7          SE Channel
 4: 3          Excite all reps w/Exchan 3
 5: 2          Delay (units 0.01 sec)
 6: 2500       mV Excitation
 7: 17         Loc [ WDdeg     ]
 8: 0.142      Mult
 9: 0          Offset

;Gas Stoves
;Gas Heater
;Radiant Heat Panels
;Power

;OUTPUT -- HOURLY
17:  If time is (P92)
 1: 0          Minutes (Seconds --) into a
 2: 60         Interval (same units as above)
 3: 10         Set Output Flag High

18:  Resolution (P78)
 1: 1          high resolution

19:  Real Time (P77)
 1: 1110       Year,Day,Hour/Minute

20:  Average (P71)
 1: 7          Reps
 2: 1          Loc [ TCcsfam   ]

21:  Average (P71)
 1: 6          Reps
 2: 12         Loc [ MultRef   ]

*Table 2 Program
  02: 0.0        Execution Interval (seconds)

*Table 3 Subroutines

End Program

-Input Locations-
1 TCcsfam   0 1 0
2 TCfam     0 1 0
3 TCcsmbed  0 1 0
4 TCmbed    0 1 0
5 TCbath    0 1 0
```

```
 6 TCbed      0 1 0
 7 TCdryer    0 1 0
 8 TC8        0 0 0
 9 TC9        0 0 0
10 TC10        0 0 0
11 TC11        0 0 0
12 MultRef    0 4 3
13 SolarRad   2 1 1
14 RHout      2 2 1
15 Tout       2 2 1
16 WSmph      2 2 1
17 WDdeg      2 2 1
18 _____  2 1 0
19 _____  2 1 0
20 _____  2 0 0
21 _____  2 0 0
22 _____  2 0 0
23 _____  2 0 0
24 _____  2 0 0
25 _____  2 0 0
26 _____  2 0 0
27 _____  2 0 0
28 _____  2 0 0
29 _____  2 0 0
30 _____  2 0 0
31 _____  2 0 0
-Program Security-
0000
0000
0000
-Mode 4-
-Final Storage Area 2-
```

Sample Data Record

```
{blank line}
112,1996,204,1430,21.401,21.986,22.33
112,1996,204,1430,21.381,22.357,22.778
112,1996,204,1435,21.363,21,21.195
113,1996,204,1440,21.319,13.235,20.401,20.468
113,1996,204,1445,21.306,13.237,20.447,20.497
113,1996,204,1450,21.295,13.241,21.375,21.468
113,1996,204,1455,21.326,13.242,21.846,21.978
113,1996,204,1500,21.372,13.242,21.979,22.117
113,1996,204,1505,21.42,13.244,22.051,22.192
113,1996,204,1510,21.469,13.246,22.103,22.244
113,1996,204,1515,21.516,13.247,22.145,22.286
113,1996,204,1520,21.559,13.249,22.179,22.32
113,1996,204,1525,21.6,13.251,22.209,22.348
113,1996,204,1530,21.638,13.252,22.236,22.373
113,1996,204,1535,21.672,13.254,22.26,22.394
```

Appendix H—Temperature Profiles and Precipitation Graphs

November and December
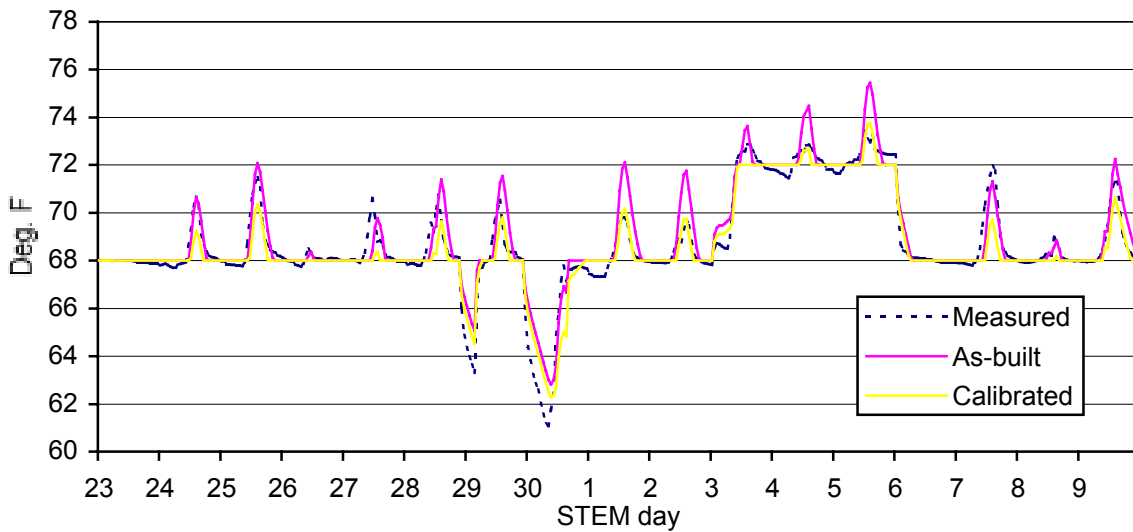
Figure H1. Measured and modeled indoor temperature profiles during STEM period
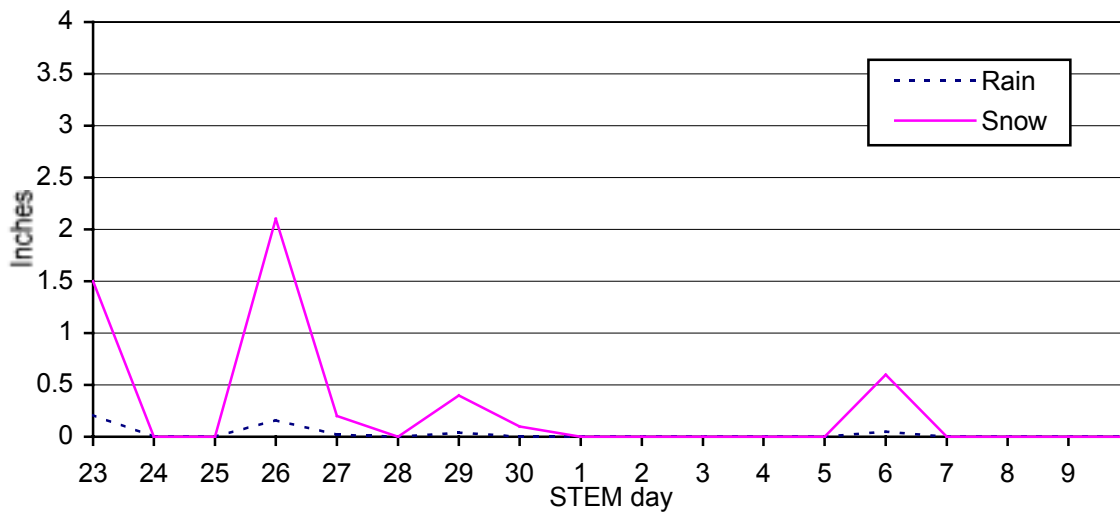
Figure H2. Snow and rainfall levels during STEM period [24]

January
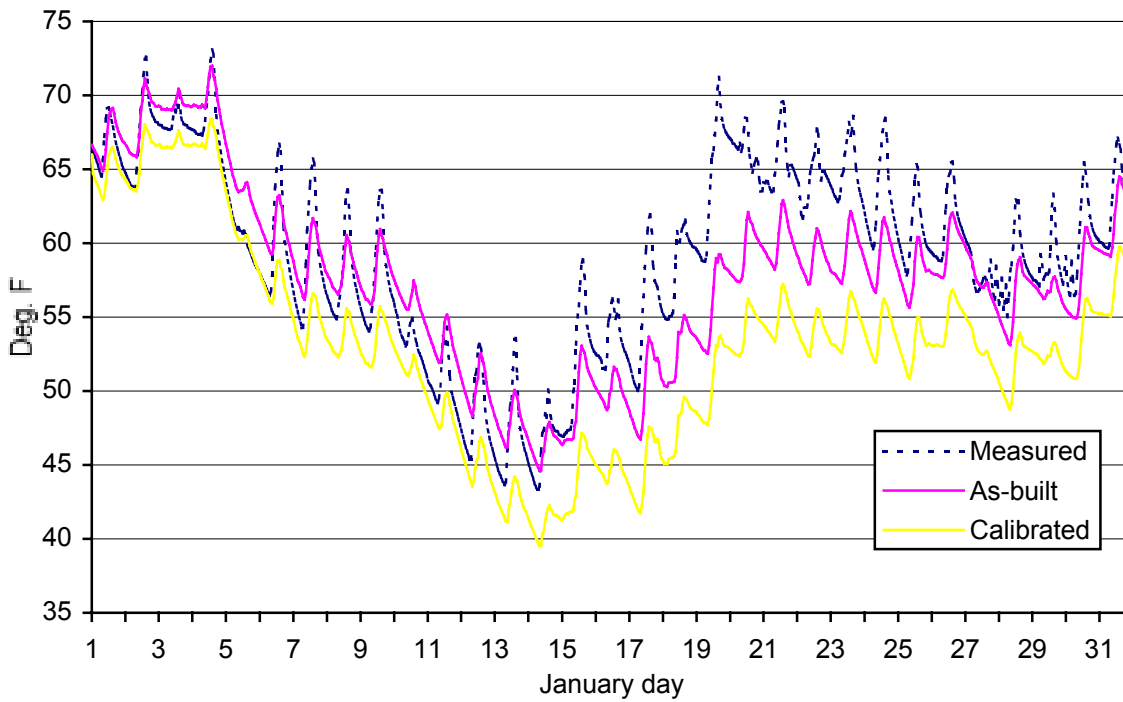
Figure H3. Measured and modeled indoor temperature profiles for January 1997
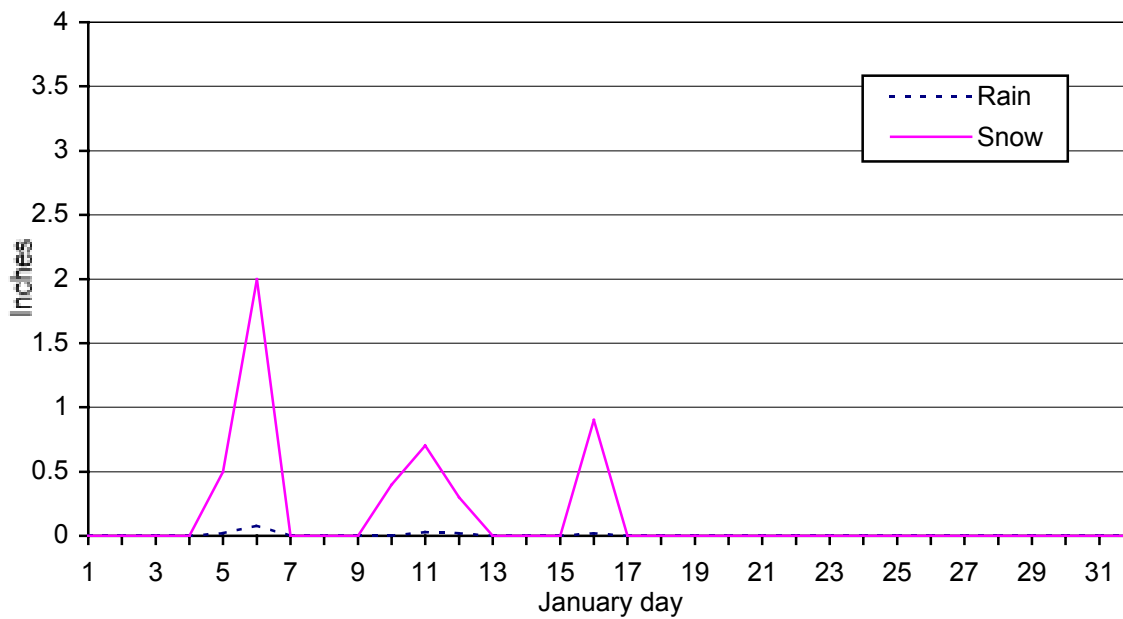
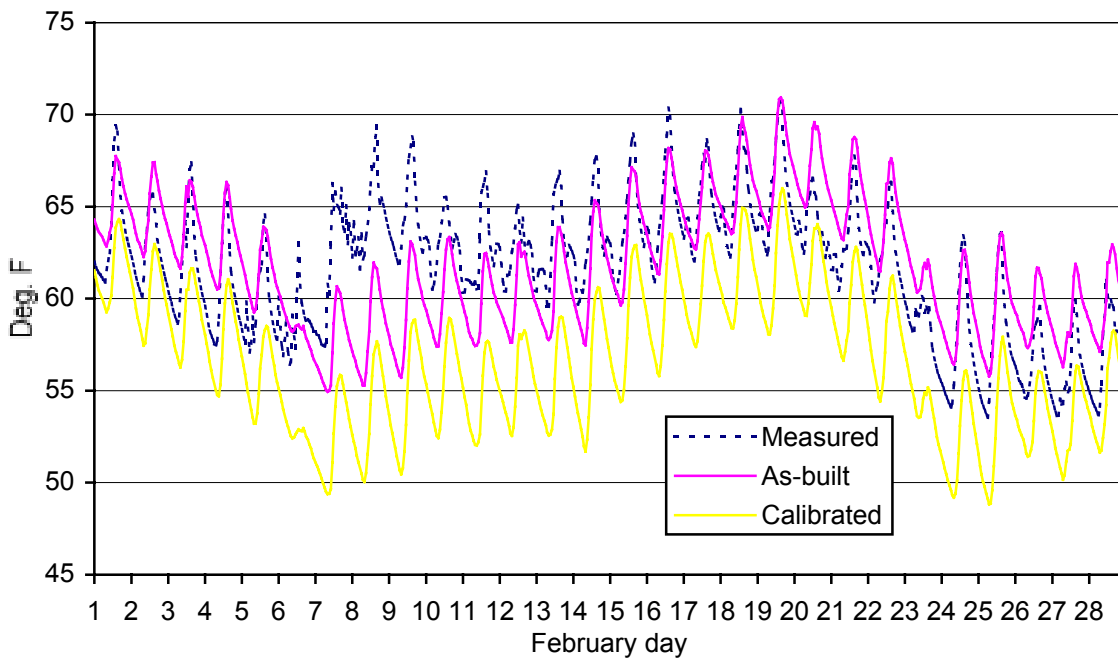Figure H4. Snow and rainfall levels for January 1997

February

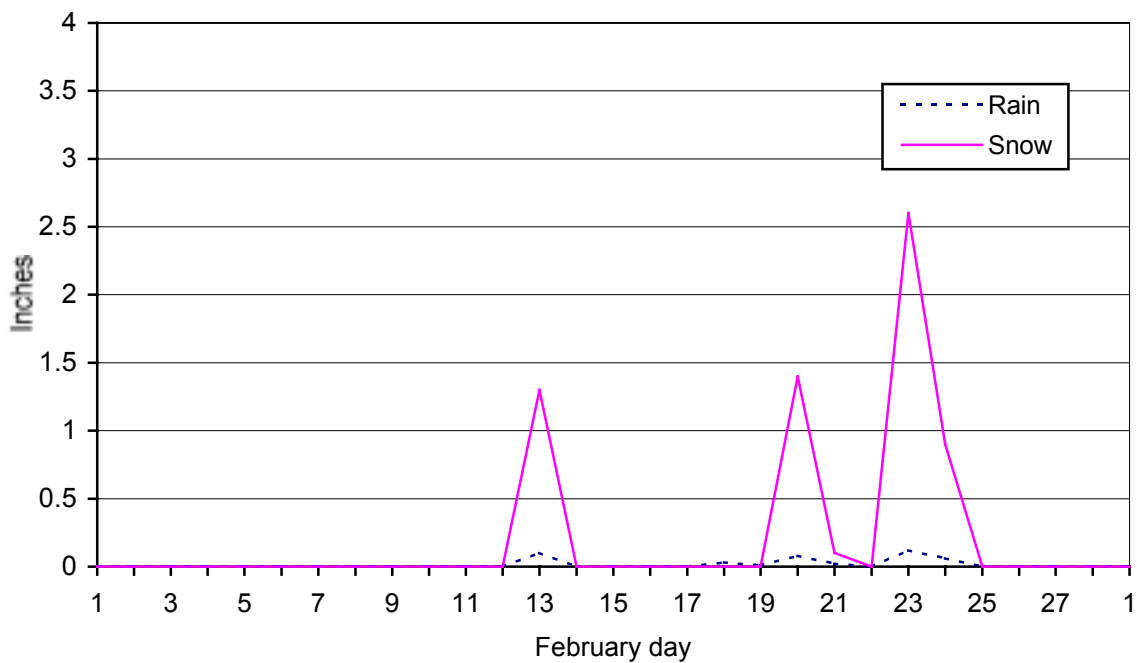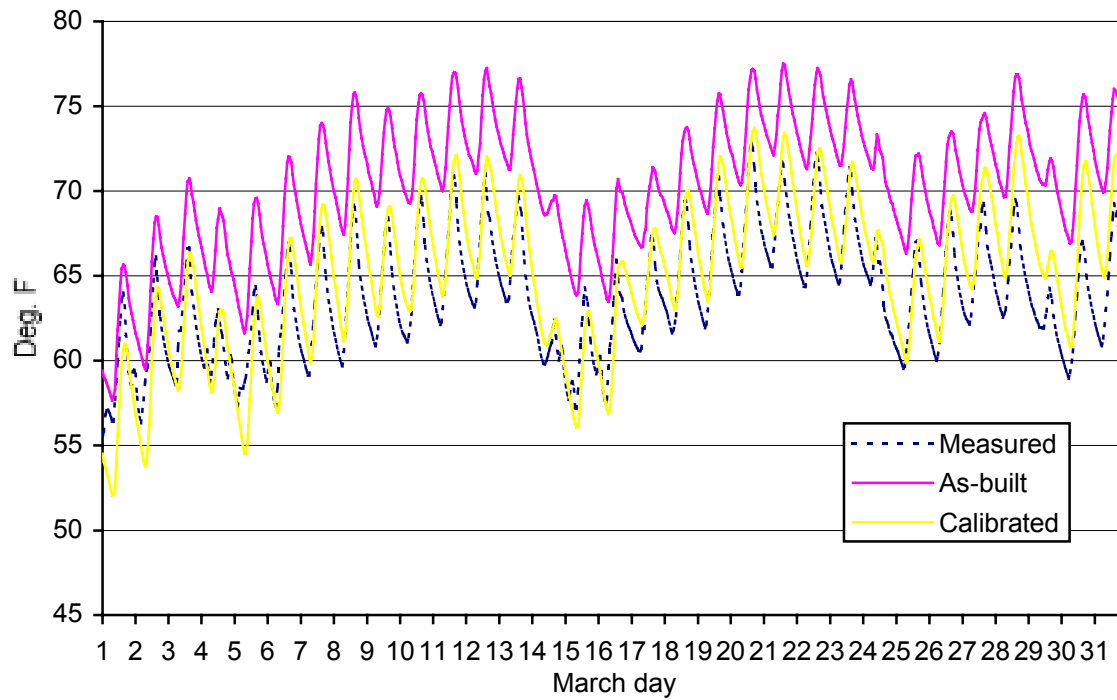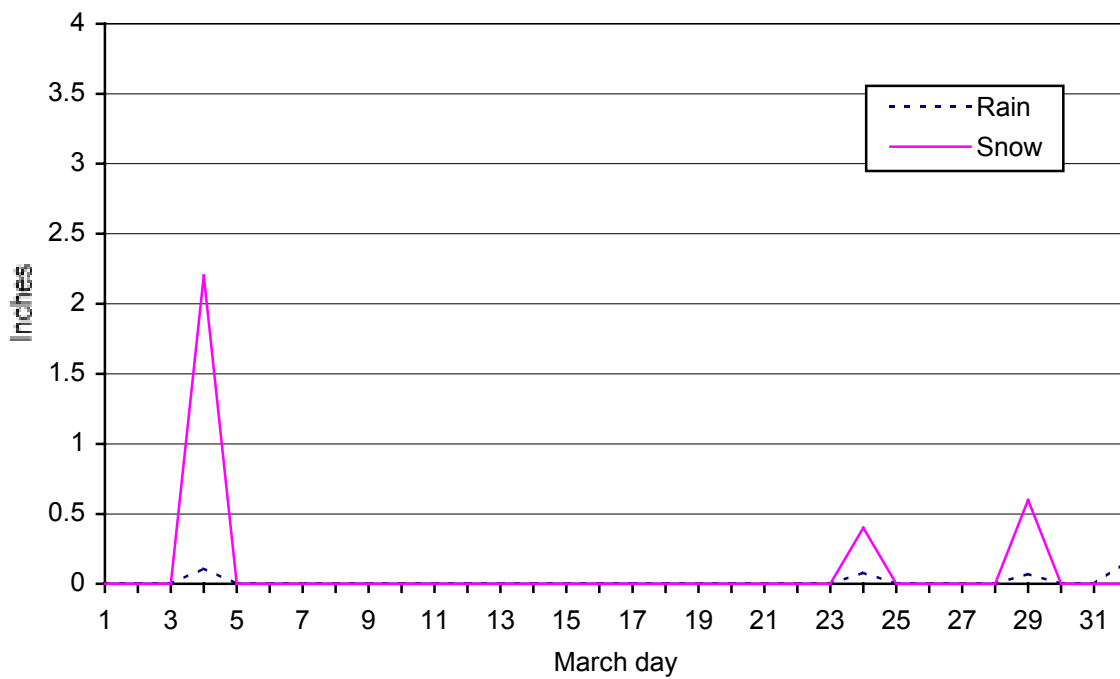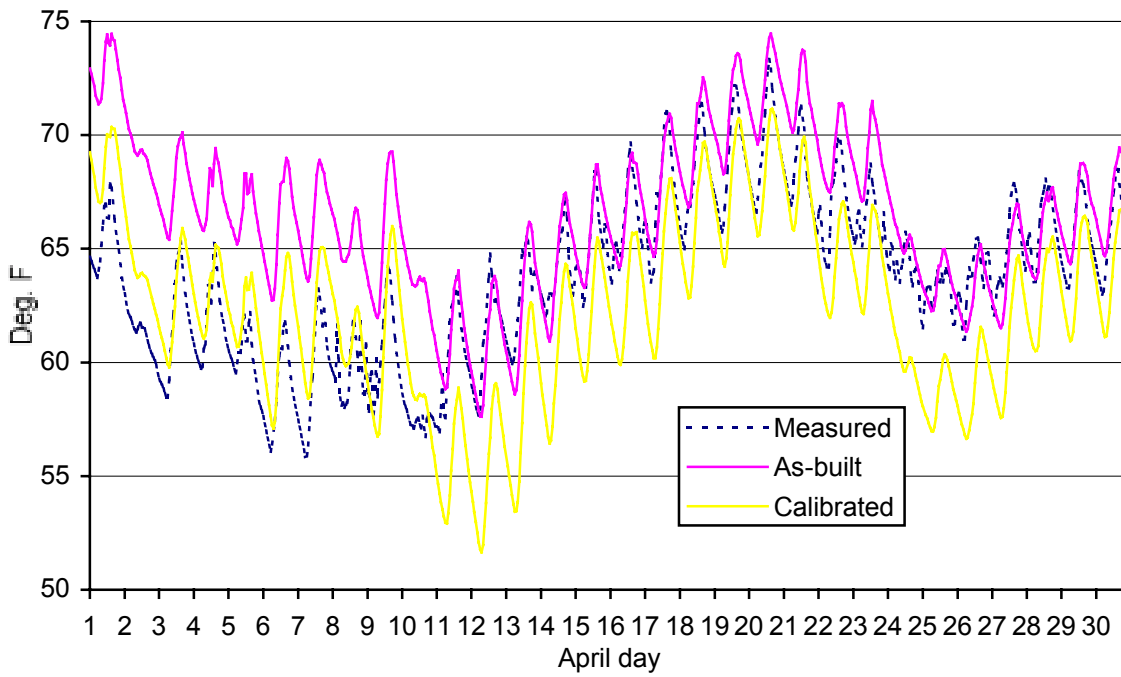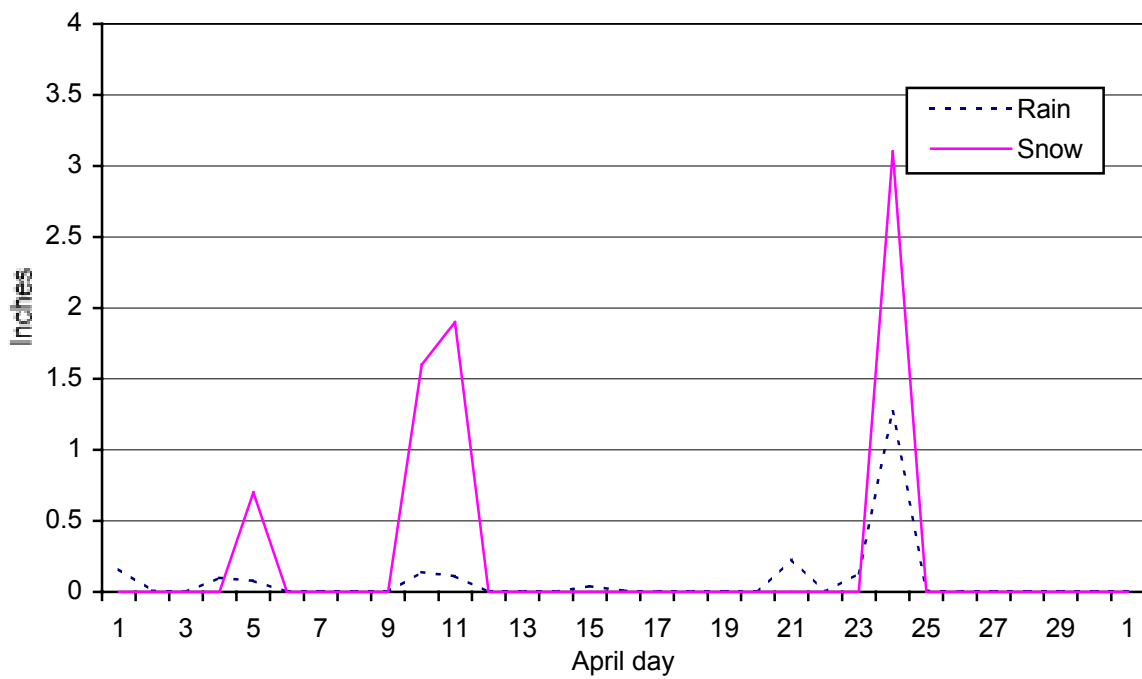Figure H5. Measured and modeled indoor temperature profiles for February 1997

Figure H6. Snow and rainfall levels for February 1997

March

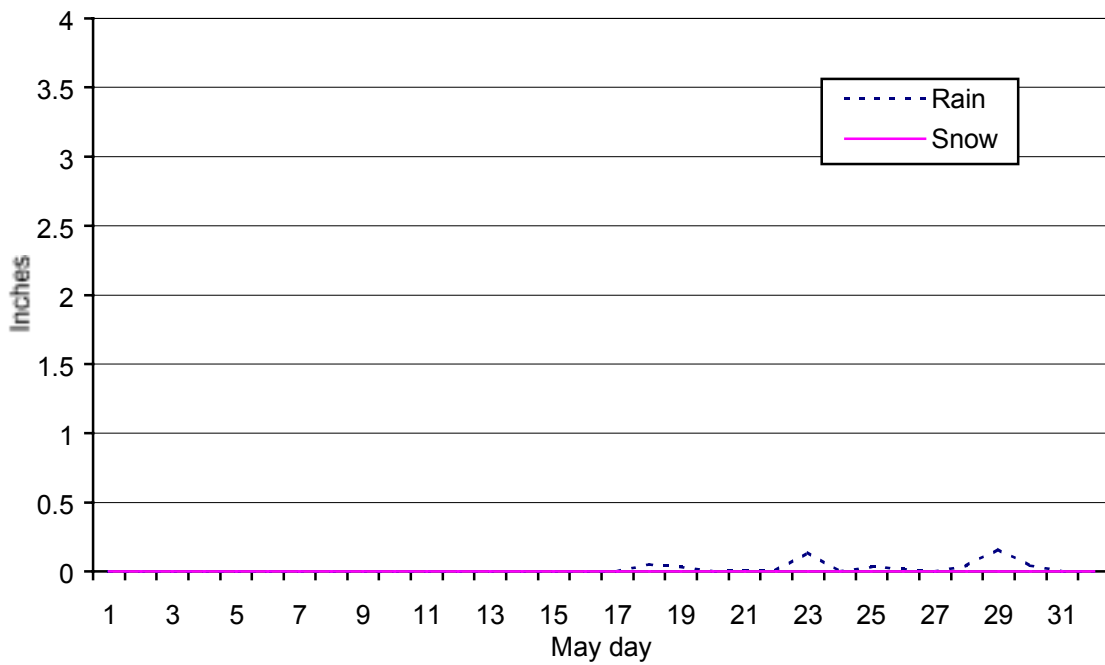Figure H7. Measured and modeled indoor temperature profiles for March 1997

Figure H8. Snow and rainfall levels for March 1997

Figure H9. Measured and modeled indoor temperature profiles for April 1997

Figure H10. Snow and rainfall levels for April 1997

May
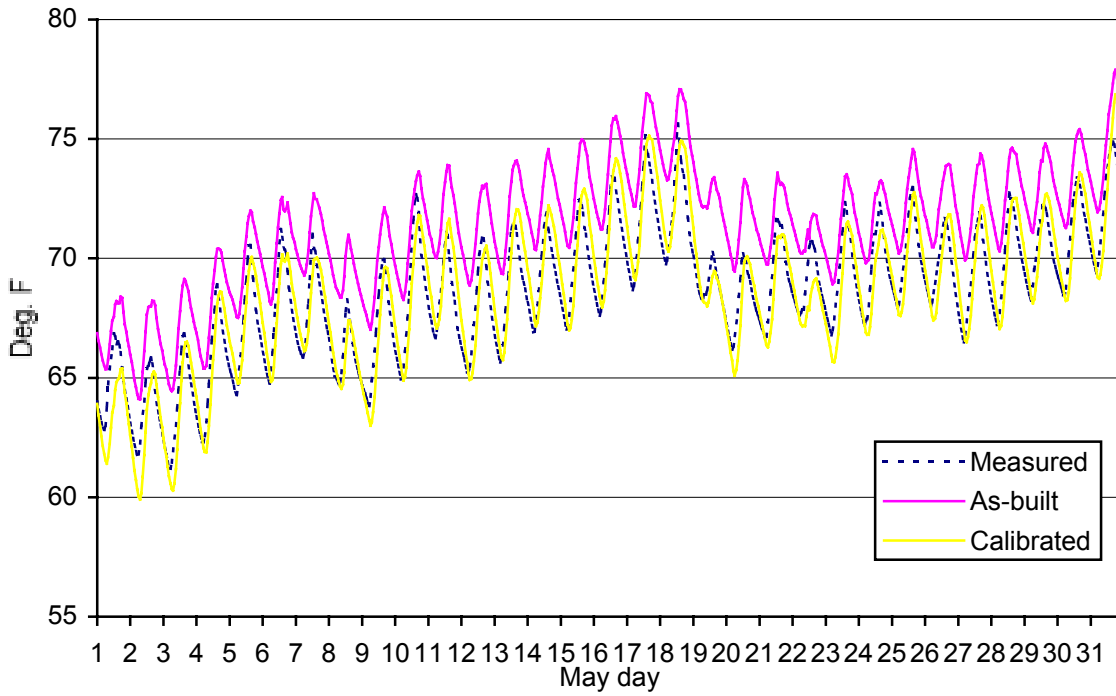
Figure H11. Measured and modeled indoor temperature profiles for May 1997

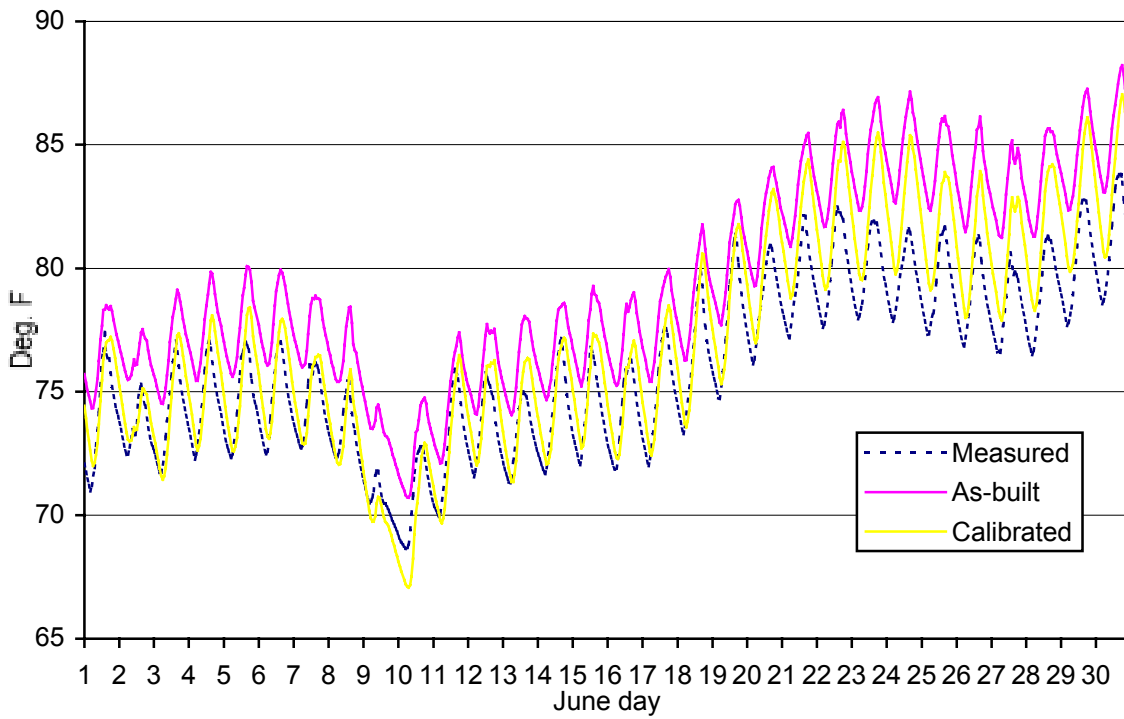Figure H12. Snow and rainfall levels for May 1997

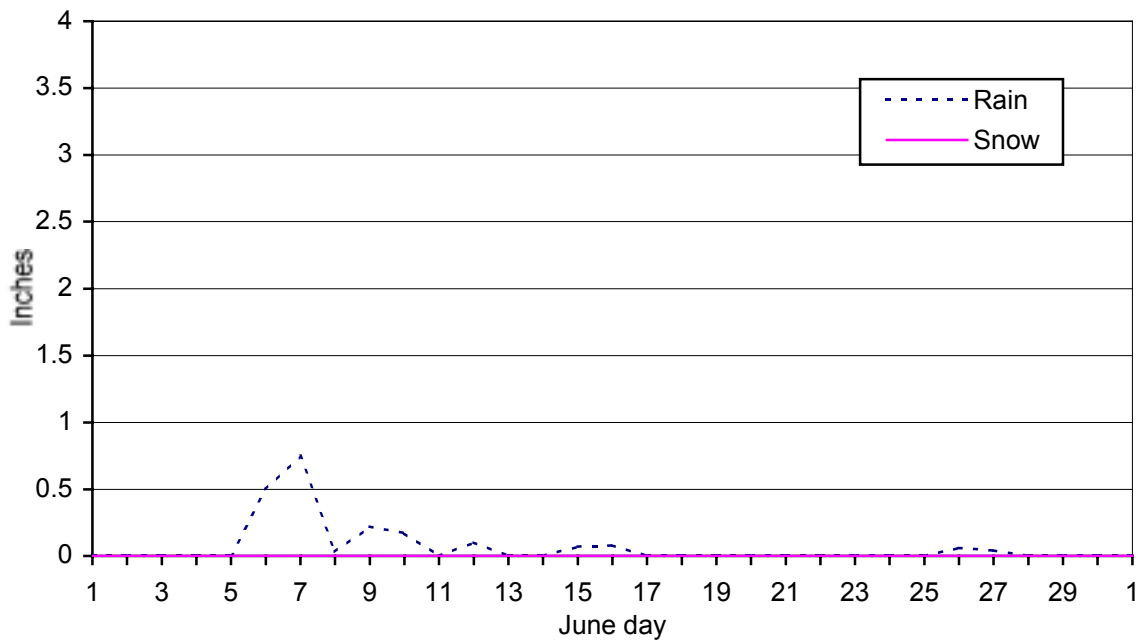Figure H13. Measured and modeled indoor temperature profiles for June 1997

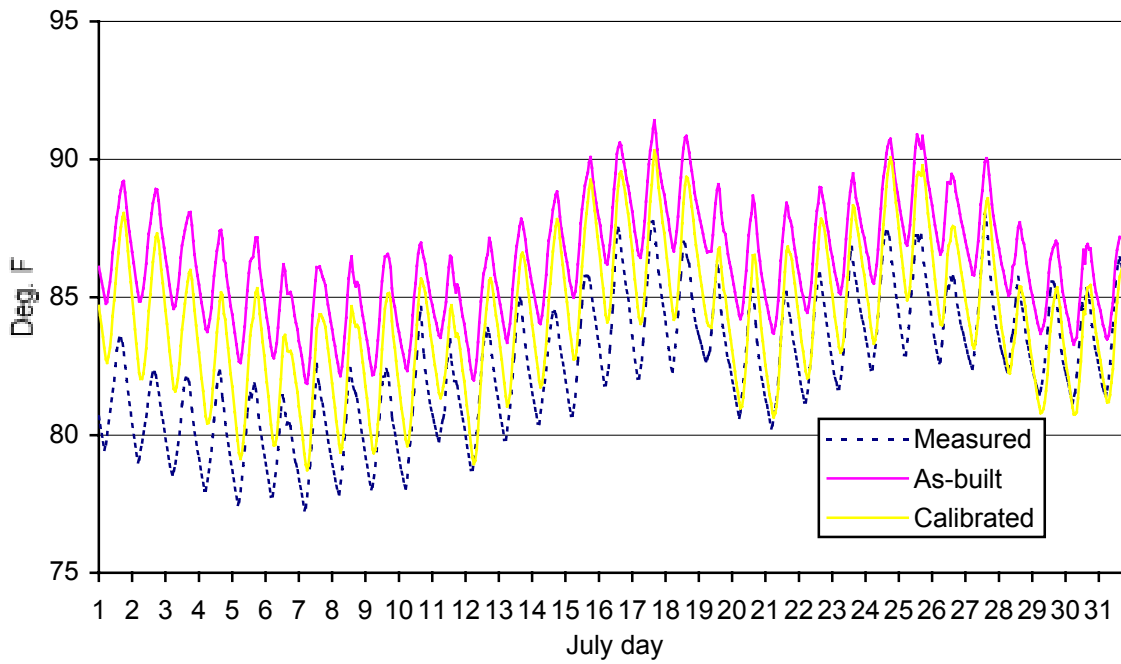Figure H14. Snow and rainfall levels for June 1997

July

Figure H15. Measured and modeled indoor temperature profiles for July 1997
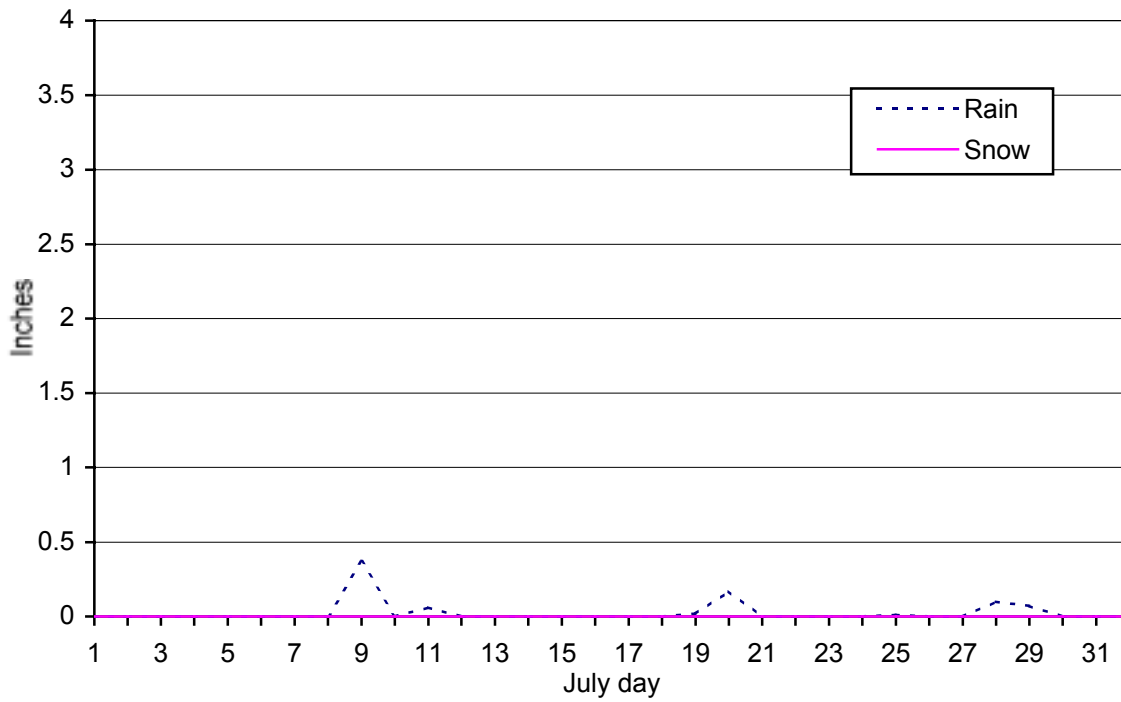

Figure H16. Snow and rainfall levels for July 1997
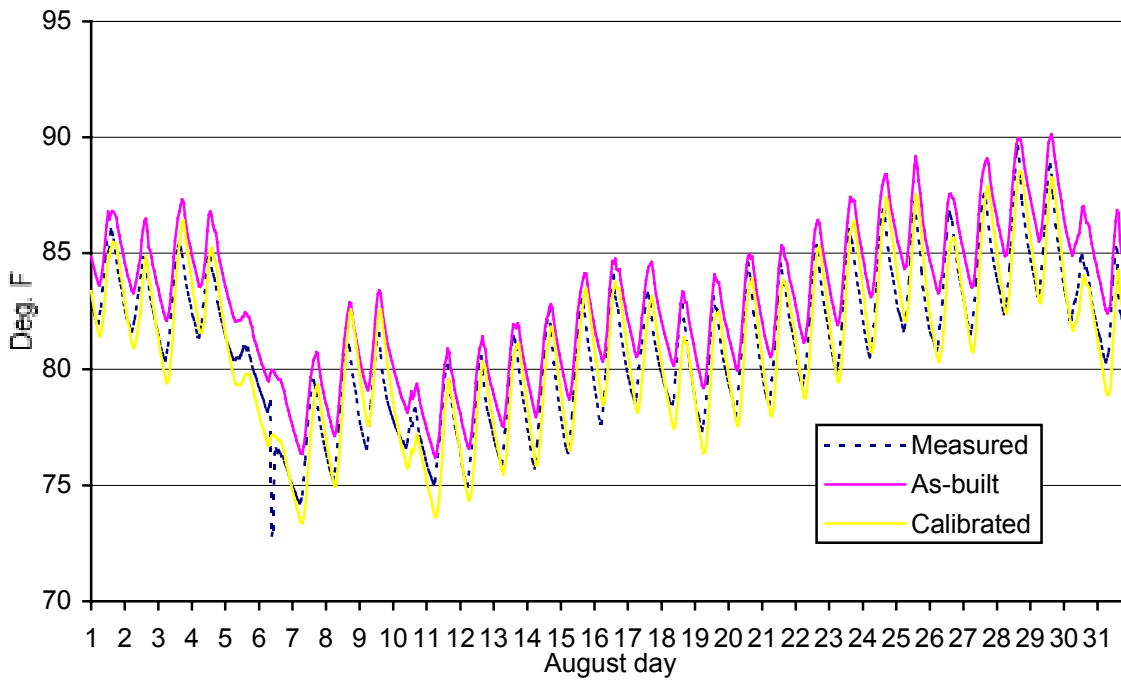
August

Figure H17. Measured and modeled indoor temperature profiles for August 1997
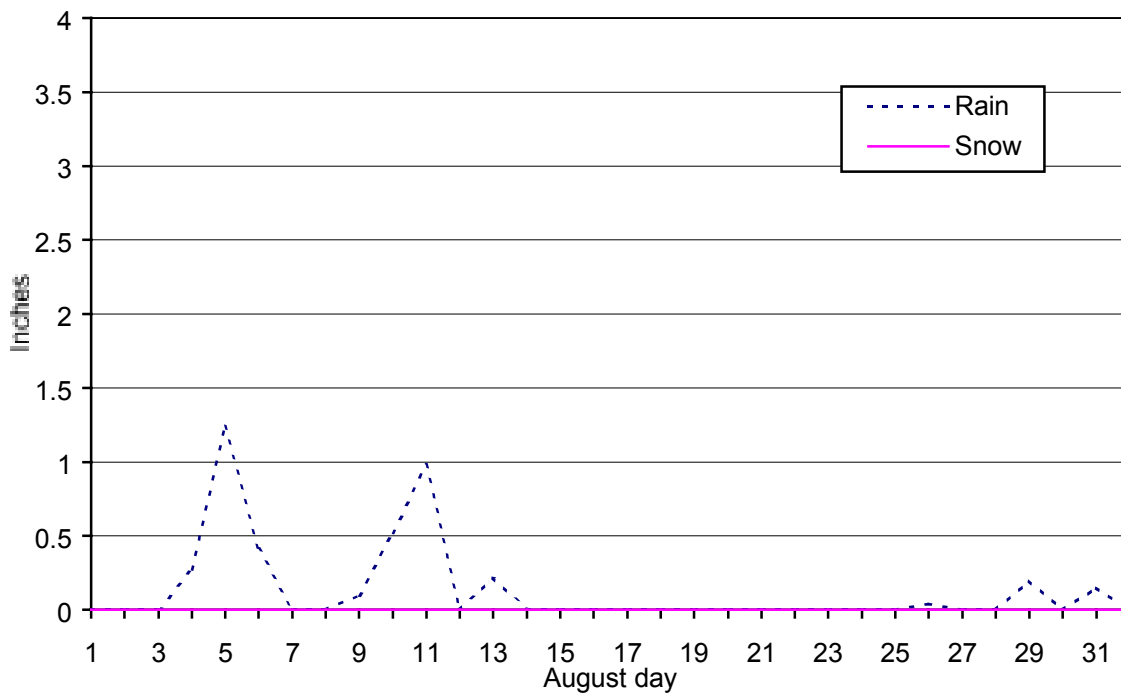

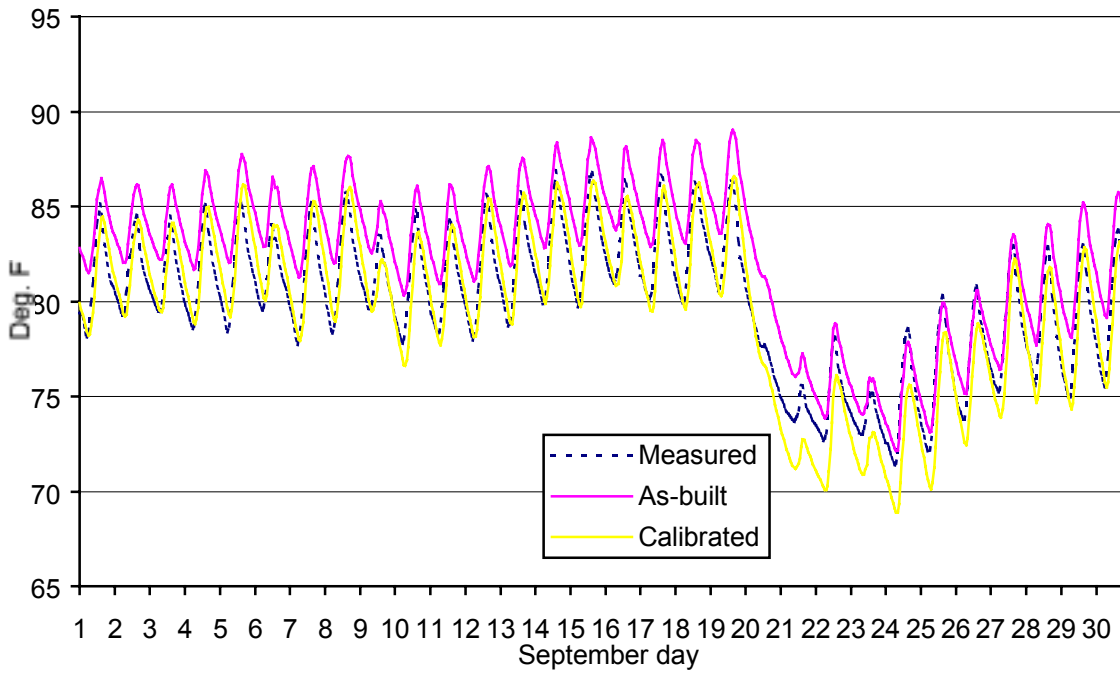Figure H18. Snow and rainfall levels for August 1997

September

Figure H19. Measured and modeled indoor temperature profiles for September 1997
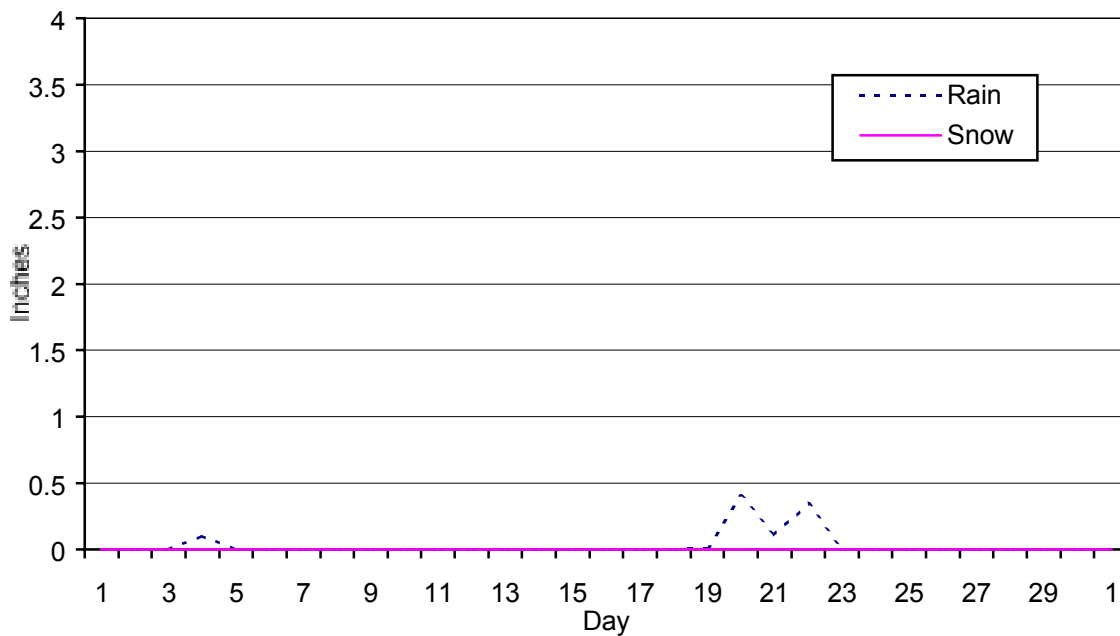

Figure H20. Snow and rainfall levels for September 1997

Appendix I—Model Descriptions

Several models that were used in different phases of this project are defined as follows:

Original: The original model is based on plans for an 1,120 ft^2 (104 m^2) house. The design of this house was fine-tuned in the design phase [4], but the house was never built.

Preconstruction: The preconstruction model is based on the 1870 ft^2 (174 m^2) plans of Tierra I prior to construction. Most of the preliminary analysis of Tierra I was done using this model.

As-built: The as-built model reflects changes to the plans that occurred during construction. Little analysis is done using this model.

Calibrated: The as-built model was calibrated to match short- and long-term performance data. The calibrated model provides a more accurate model of the house.

Improved: The calibrated model was improved to try to meet the 70% savings requirements. The improved model uses increased quantities of insulation and south-glazing area while maintaining the changes to material properties assumed in the calibration process.

Base case: The base case model conforms to HERS/MEC specifications. There was one base case (1,120 ft^2) in the design report and a new one in this report that was redone to match the size of Tierra I (1,870 ft^2).

Appendix J—ELA and ACH Calculations

ELA calculation
From Figure 17 the airflow rate at 4 Pa is 220 cfm. ELA = 220 cfm x 0.2835 = 62.37 in^2.
ACH calculation [blower door manual]
House volume = 19448 ft^3
CFM50 = 1049.45 (from measured blower door data)
ACH50 = (CFM50*60)/volume = 3.24
ACH = ACH50/N = 0.2039
N = C x H x S x L = 15.876
C = 14
H = 0.9
S = 0.9
L = 1.4

Table J1. Blower Door Data

House Pressure Pa	Fan Pressure Pa	Ring	Flow *
60	48	A	1226.98
50	35	A	1049.45
44	32	A	1003.94
35	23	A	852.59
34	282	B	996.43
30	234	B	906.58
26	205	B	847.81
23	172	B	775.70
21	141	B	701.42
20	114	B	629.82
15	73	B	502.54
34	230	B	898.69
29	215	B	868.51
27	192	B	820.14
27	162	B	752.52
22	125	B	659.90
19	91	B	561.89
15	56	B	439.39

* Calculated using formulas from *Blower Door System Manual* [25]

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13. ABSTRACT *(Maximum 200 words)*
A low-energy concrete house was designed using passive solar strategies to consume 70% less heating and cooling energy than a base case that conformed to the 1996 Home Energy Rating System (HERS) and the 1995 Model Energy Code (MEC). The performance of this house was then evaluated using computer simulations and measured data.

The house, Tierra I, was monitored from July 22, 1996, through October 14, 1997. A Short Term Energy Monitoring (STEM) test was done November 19 to December 10, 1996. Computer simulations of the house were done using SUNREL, an updated version of the hourly data simulation package SERI-RES. The SUNREL model of the house was calibrated using both short- and long-term data.

The house achieved energy savings of 56%, below the goal of 70%. The lower than expected savings resulted from problems with the window modeling. As a result, during the design phase the solar gains were overestimated causing an underestimate in the level of insulation necessary to achieve the savings goal. For very low-energy passive solar buildings, it is apparent that very accurate window modeling is required. It also became apparent that accurate ground models are required as well because ground-heat loss accounts for a significant portion of the total heat loss in low-energy buildings.

14. SUBJECT TERMS
Low-energy buildings; house design; passive solar; SUNREL; Tierra I; STEM; HERS

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